The Effects of Academically Productive Talk in Group Discourse in a Virtual Internship for Engineering

The Effects of *Academically Productive Talk* in Group Discourse in a Virtual Internship for Engineering

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A Thesis Presented to the Faculty
of the Graduate School of Education of Harvard University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Education

2016

Dedication

This dissertation is first dedicated to the living memory of my grandparents (Richard Jasaitis, Richard Hartung, and Marie Hartung), my grandmother (Jane Jasaitis), my parents (Donna Hartung, Robert Hartung, and Judi Hartung), my in-laws (Ron Simon and Rosemary Simon), and my wife, Kristin Russo. With great love and appreciation – thank you for always encouraging, and allowing, me to pursue my passions.

Second, I would like to dedicate the spirit of this work and effort to my two beautiful children, Rowan Eliot Russo-Hartung and Hazel Maeve Russo-Hartung, who have only known a Father working towards this goal. I hope that this undertaking of mine can serve as encouragement for you both to pursue your passions wherever they may take you, to find beauty in learning, to nurture your curiosity, and to embrace the wondering and wandering that makes for a fertile, fulfilling, and fascinating life. I love you both dearly.

Acknowledgements

I owe a great deal of thanks to a number of people who have supported me along the way to complete this study.

I would like to express my sincere gratitude to my dissertation committee - Professors Chris Dede and Terry Tivnan from Harvard Graduate School of Education, and David Shaffer from University of Wisconsin, Madison - for the conceptual and methodological expertise, insight, and enthusiasm that provided critical guidance and support in the completion of this dissertation. I would also like to acknowledge the generous time and committed attention David provided throughout this process as an external committee member – his guidance and mentorship has been central in the construction of my unique academic identity.

Thanks are also due to EGG/GAPS at the University of Wisconsin-Madison for allowing me access to the rich dataset used for analysis in this thesis. In particular, I would like to express my appreciation to Golnaz Arastoopour and Wesley Collier who offered their time to provide me with critical insights and technical support that facilitated my understanding of the methodology and interpretation of Epistemic Network Analysis. It is also important to acknowledge that the data provided by EGG/GAPS used in this study was funded in part by the Macarthur Foundation and by the National Science Foundation through grants DUE-1225885, DRL-0918409, DRL-0946372, DUE-0919347, EEC-0938517, and REC-0347000, and that the opinions, findings, and conclusions in this thesis do not reflect the views of the funding agencies, cooperating institutions, other individuals, or those of EGG/GAPS.

I would also like to express my gratitude to William Johnston, formerly a research specialist at HGSE, for the technical support and methodical insights he provided during the early phases of data analysis used in this study, and to Ron Simon for the critical role he played in coding the qualitative data used in this study to establish inter-rater reliability, and for his dedicated and timely efforts to extract and organize data when I needed it most.

Additionally, I would like to acknowledge that this study would not have been possible without the broad support and influence of others in my academic and professional life. To Kay Merseth, a heartfelt thank you for your advocacy for my needs, the protection of my interests, and your boundless encouragement and enthusiasm that has sustained me since I arrived at HGSE. To the good people of the Learning Innovations Laboratory (LILa) at Project Zero, thank you for welcoming me into your community of learning and practice. I would like to especially thank Daniel Wilson - your collaboration and friendship has been some of the most enjoyable and formative during my doctoral studies, and your mentorship has played a central role in shaping who I am, and what I value, as a researcher. To Nancy Mann, Erika Neilson Andrew, Allison Rowland (my biggest fan), and Kristin Russo – thank you for the opportunity to lead and learn with you. Our work together over the years deepened and challenged the ways I understand and think about approaches to leadership and practice that make a difference in the lives of children, and the adults who work on their behalf. Thank you also to my family and friends at large for their support and encouragement through this process, as well as to my peers and colleagues in the broad field of education whose ongoing work with schools and leaders, teachers and children continues to serve as an inspiration for my own work and interests.

Finally, I wish to offer a very special and loving thank you to my wife, Kristin Russo - this endeavor would not have been possible without your patience, ever-present encouragement, unyielding confidence in my choice and capacity to pursue this work, and your willing support, in all its forms, over these many years. Onward!

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Abstract

Skills associated with collaborative problem solving (CPS), especially in STEM-related disciplines, are increasingly regarded as essential for success in work and life. In the last decade, simulation-based games have emerged as rich environments for the situated learning of such skills, and are instrumental in the study of CPS because they provide rich data for detailed analysis of discourse and social interaction. One type of social interaction, *Academically Productive Talk* (APT), has been found to support collaborative activity, encourage knowledge integration, and promote academic gains for individuals. However, little is known about the relationship between APT and how groups develop complex STEM thinking. Additionally, despite evidence that students' attitudes affect social interaction during collaborative activity, little is known about how collaborative social interaction may affect students' attitudes.

The primary goals of this study were to examine CPS discourse in order to: 1) investigate the relationship between the qualities and characteristics of how groups talk and what groups talk about; and 2) understand whether how groups talk effects a change in students' attitudes. To meet these aims, this study paired conversation analysis with an innovative analytical methodology, Epistemic Network Analysis (ENA), to study groups' endogenous use of APT and its relationship with substantive qualities of group discourse in the virtual simulation of professional practice in engineering, *Nephrotex*.

This study presents empirical evidence that, (1) specific APT-style contributions were effective for introducing critical, domain-specific evidence into student discourse, and (2) more use of APT in group discourse resulted in better knowledge integration of

human-centered design constraints (i.e., their client's needs; their consultants' interests) and data analysis. These findings varied in terms of how, when, and what type of, integration occurred. No evidence was found to suggest that students' participation in groups that engage in more APT affects a positive change in their attitudes. A better understanding of the effects of APT in a simulation-based game environment can be used to inform the ongoing research and development of technologies capable of shaping and observing discourse as it occurs in virtual environments for learning, and that support students' development of CPS skills.

Chapter One

Introduction

1.1 Background and Context

Educational practice in America has changed little in the 29 years since Resnick (1987) characterized the disparity between "school" learning and the kinds of learning commonly experienced and expected in life outside of schools. Her first observation is that schoolwork and learning focus almost exclusively on individual efforts as opposed to collaborative ones. Second, she notes that schoolwork tends to emphasize "unaided thinking" as opposed to the use and application of discipline specific tools and resources. And finally, in school she argues that students are taught through exposure to abstract/symbolic, rule-based thinking and general/theoretical skills as opposed to interaction with authentic, complex scenarios representative of the kinds of situations and problems they may encounter in their personal and/or work lives. In short, our current educational practice "remains doggedly committed to imparting facts and algorithms" (Perkins and Salomon, 1989, p. 23) with little accounting for the ongoing shifts in the types of knowledge and skills society values as outcomes in education, coupled with changes in characteristics and environments that learners bring to schools today.

However, as Vendlinski et al. (2008) point out,

> …educational stakeholders are increasingly asking that students not only demonstrate that they can re-present a corpus of learned knowledge but also demonstrate the reasoning necessary to apply that knowledge to solve problems likely to be faced in future educational and life pursuits (p. 309).

Foreshadowed in the work of Murnane and Levy (1996) and the SCANS 2000 report

(Department of Labor, 1991), researchers and practitioners from a variety of domains are converging on the need for students to engage in "deeper learning," which the NRC (2012) characterizes as the process of developing "broad, transferable skills and knowledge, often referred to as 21st century skills" (p. 1-1) and is "the process through which an individual becomes capable of taking what was learned in one situation and applying it to new situations (i.e. transfer) and to the solving of new problems" (p. Sum-4).

Many organizations and associations have developed and recommended frameworks that define these skills in order to inform policy, guide the work of schools, and orient their instructional approaches and outcomes to meet the needs of 21st century learners and society (c.f., Partnership for 21st Century Skills, 2006; the American Association of College and Universities, 2007; Hewlett, 2010a; 2010b; Assessment and Teaching of 21st Century Skills (ATC21S); NRC, 2012). In his review of many of the aforementioned frameworks, Dede (2010) concludes that they are largely consistent in terms of the kinds of skills that should be incorporated into educational practice. More recently, the field has converged on a conception of deeper learning as the imparting of skills that can be roughly organized into three central domains: the cognitive (e.g., processes and strategies, critical thinking, reasoning, information literacy, etc.), the intrapersonal (e.g., metacognition, flexibility, work ethic, initiative, etc.), and the interpersonal (e.g., teamwork, collaboration, communication, leadership, etc.) (Dede, 2014; Hewlett, 2010a, NRC, 2012, ATC21S)

Some argue that the call to incorporate deeper learning competencies in school learning too heavily privileges skills and project-work disconnected from mastery of content knowledge (Common Core, 2011). However, a careful reading of the literature put forth by proponents of deeper learning shows that their proposals and frameworks are not only *inclusive* of the mastery of content area knowledge, but present evidence that this mastery is the key lever through which to impart and assess these competencies. The arguments in favor of deeper learning emphasize a corpus of skills and transferable knowledge that form the backbone of a student's preparation to pursue a broad range of life choices and passions. These competencies comprise what effective education has always provided students and represent, "dimensions of human competence that have been valuable for many centuries, rather than skills that are suddenly new, unique and valuable today" (NRC, 2012, p. 3-9; see also: Silva, 2009; Rothman, 2011; Alliance, 2011).

In particular, research finds statistically significant, positive correlations between deeper learning and a broad range of adult outcomes (NRC, 2012) including personal and work outcomes (Cascio, 2010), civic engagement (Bedolla, 2010), self-regulated learning (Wolters, 2010), and resilience (Masten et al., in Coatsworth, 2010). Furthermore, research suggests that enhancing instruction with goals that reach beyond content knowledge by incorporating deeper learning competencies contributes to lasting learning experiences (Bergman, 2010) and supports the development of a mindset that allows for individuals to develop self-sustaining strategies for learning, as well as become effective in professional and leadership roles in society (Finegold and Notabartolo, 2010; Dweck, 2009; Boyatzis, 2008; Levy and Murnane, 2006).

Unfortunately, there is little consensus on best practices that can be used as models for teaching or assessing these skills (Markham et al., 2003; Darling-Hammond &

Adamson, 2010), although initial work has begun to identify and codify approaches (c.f., EdLeader21; Innovative Teaching and Learning Research; ACT21S; Lampert (in press); Darling-Hammond, Noguera, & Friedlaender (2015). Furthermore, while most OECD countries have included so called 21st century skills in their regulations, guidelines, and/or curriculum reform initiatives, there are no clear assessment policies or practices in place at scale. This is due, in large part, to a dearth of "definitive research on the range of skills and behaviors that have come to fall under the headings of 'deeper learning' and '21st century skills'" (NRC, 2010, p. Sum-2) and to a lack of measures by which to assess them (Finegold and Notaboartolo, 2010; Ananiadou and Claro, 2009; Boyatzis, 2008).

What is made clear in recent publications, however, is teachers and schools should embrace and deploy a suite of digital technologies that can facilitate the types of practices (e.g., interdisciplinary investigations; collaborative problem solving; personalized and connected learning) that have been found to further such outcomes (Dede, 2014). This is especially true given the ever-changing landscape of the types of learners we see in schools today, whose experiences with technology can be leveraged and extended by learning that incorporates tools and media providing real-time access to information and knowledge sharing, thus preparing them for a new world of work that uses technology to interact and distribute tasks and resources across time and space (Dede, 2014; Prensky, 2001).

In particular, the development of competency in *collaborative problem solving* (CPS) - skills associated with collaboration, communication, and problem solving - holds prominence in popular interest, practice, and research regarding its value as a learning processes and as a capability useful in learning, work, and life (OECD, 2013; NRC, 2012; Levy and Murnane, 2006). One recent definition for CPS, provided by the OECD (2013) for use in the administration of the PISA 2015, is:

> …the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills, and effort to reach that solution" (p. 6).

The three core competencies that undergird CPS are the ability to (1) establish and maintain shared understanding, (2) take appropriate action, and (3) establish and maintain team organization (OECD, 2013). Relatedly, there is a range of intra- and inter-personal (i.e., social) skills detailed in the literature (c.f., Griffin at al., 2011; 2012; O'Neill et al., 2003; OECD, 2013) that are integral to CPS competency and that occur through social interaction in groups. These social and cognitive skills include:

1) participation and cooperation (i.e., contributing knowledge to the group);
2) task regulation (i.e., understanding the information and resources needed to complete the task);
3) knowledge building (i.e., contributing information and skill-based knowledge);
4) social regulation (i.e., negotiating misunderstandings and conflicts of ideas);
5) perspective taking (i.e., considering the ideas put forth by others);
6) using judgment, identifying alternatives, and evaluating consequences; and
7) exercising leadership (i.e., coordinating activities and of the team).

As such, the current interest in CPS highlights the importance of a continued "zooming in" on the black box of collaboration, discourse, and situated social interaction in the context of problem solving. To understand these processes, researchers suggest using mixed-methods analysis of conversational data to "make visible" the learning of individuals and small groups (Dillenbourg, 1999; Stahl, 2006) by observing their participation in "concrete activities directly and identifying methodic patterns endogenous to the activities themselves" (Moore, 2012, p. 232).

Various proposals exist to address the gulf between the competencies we want students to obtain and the approaches we have to get them there. One promising medium is "serious games," a term used to distinguish the use of an immersive digital environment designed as a game to explicitly educate or train (Shute et al., 2009). Such games have received extensive treatment in the literature regarding how they provide powerful learning environments and about their potential to teach, measure, and validate the development of deeper learning competencies. Importantly, they are an example of an environment that "inverts" the traditional model of learning by proposing that through learning to *be,* students begin to learn *about* (Thomas and Brown, 2009).

1.2 Objectives of Dissertation

Within this broad landscape of research, the aim of my study was to examine the different effects of collaborative discourse in a problem-solving task within a serious game environment by using conversation analysis - an empirical and inductive approach concerned with how social interaction is organized in general, and how it is accomplished through "talk-in-interaction" – coupled with Epistemic Network Analysis (ENA). ENA is an innovative analytical methodology[1] used to measure the development of complex STEM thinking (Arastoopour et al., 2014; Choi et al., 2010). A detailed discussion of ENA is provided in Chapter 3.

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[1] Developed by *Epistemic Games Group* (EGG) and the *Games and Professional Simulations Research Consortium* (GAPS) at the University of Wisconsin-Madison. For further detail about EGG/GAPS see http://edgaps.org/gaps/.

In particular, I used this methodology to study the endogenous nature of one type of conversational interaction, *Academically Productive Talk* (APT), and its relationship with substantive qualities of group discourse to better understand how to improve and extend the affordances these virtual environments provide to support collaborative learning (Moore, 2013; Sacks et al., 1974). APT, which will be discussed further in Chapter 2, codifies a body of conversational behaviors and interactions (i.e., “moves”) that research shows promote reasoned participation, foster effective discourse, provide access to improved knowledge structures, and yield increases in academic achievement (Michaels et al., 2008; Adamson et al. 2013; Kumar and Rosé, 2011).

1.3 Structure of Dissertation

In Chapter 2, I present a review of the literature for my proposed study by discussing the different strands of research that informed my theoretical model to study the effects of *Academically Productive Talk* in discourse on the development of an epistemic frame of professional practice in engineering and on a change in students’ attitudes and perceptions (i.e., commitment, self-confidence and self-efficacy) toward engineering (Figure 1.1).

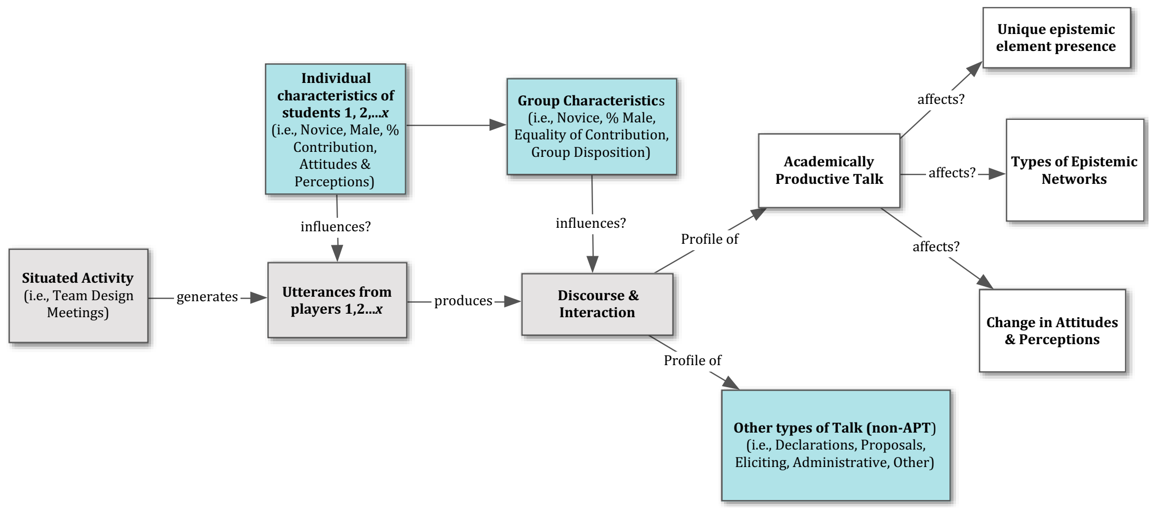

Figure 1.1. Theoretical model of the effects of *Academically Productive Talk* underlying this study.

Chapter 3 begins with a presentation of the specific research questions and hypotheses that guided this study. Following this, I present my research design that details the site/setting, the participant sample, the sources of data, and the variables and coding procedures used in this study. Chapter 3 concludes with the description of my data analytic plan.

In Chapters 4, 5, and 6, I present the results of data analyses and the empirical evidence that addresses Research Questions 1, 2, and 3, respectively. Each chapter includes a discussion specifically related to the research question considered in the chapter, and concludes with implications for practice and future research.

Finally, in Chapter 7, I provide a summary discussion of the results of my three research questions. This chapter also discussed the potential threats to validity raised in my study, as well as broad implication for practice and avenues for future research.

Chapter 2

Literature Review

A number of inter-related strands of scholarship and research informed this study about the effects of collaborative discourse on the development of an epistemic frame of professional practice in engineering, and on a positive change in students' attitudes and perceptions (i.e., commitment, self-confidence and self-efficacy) toward engineering. In the following sections, I summarize the relevant research related to this examination, which address issues in the areas of: (1) learning through conversation; (2) collaborative learning and activity; (3) *Academically Productive Talk* (APT) and collaborative discourse; (4) games and simulations for learning; and (5) epistemic frame theory and epistemic games. In my review of the literature that follows, I highlight: (1) how the development of my research questions was informed by gaps or limitations in the extant literature; and (2) and the research methods used in this study.

2.1 Learning through conversation

As summarized by Hartung and Wilson (in press), the literature on learning through conversation: (1) extends across contexts (e.g., workplace training, formal and informal learning, online environments); (2) focuses on a range of characteristics that include structural, procedural and content-related aspects of discourse; and (3) considers learning at both the individual and the group levels. Studies of conversational learning have employed a variety of taxonomies of conversational moves, or "speech acts," to study the relationship between syntactic patterns of discourse and learning (c.f., Wiley & Waters, 2005, Gunawardena et al., 1997; Soller, 2001; Ziegler et al., 2013). Some research uses "speech acts" to reflect the nature of contributions in conversation as they relate to structural roles that regulate interaction, such as turn claiming, giving/taking, listening, repairing, etc. (Bloomer et al., 2005; Mehan, 1979). In other studies, "speech acts" refer to broadly categorized types of conversational contributions (such as requesting, informing, and questioning), though this approach does not consider, for example, what type of question is being asked, or gradations in how information is being presented. In these cases, a speech act is about what an utterance does (i.e., its *functional* role in discourse), not what role it plays in the *structure* of conversational interaction. For example, asking the question, "what do you mean when you say X?" *invites* someone else to *elaborate* upon an idea or claim, which is different from asking a question such as, "what do you think about X?" (Tannen, 1990).

Such research presents evidence suggesting that different types of broadly conceived speech acts are associated with different types of outcomes. For instance, studies in workplace contexts report that narrative style contributions can facilitate knowledge transfer (Swarp et al., 2001; Leonard & Swarp, 2005) and support explicit knowledge representation in communities of practice (Brown & Duguid, 1991). Other research suggests that the use of questions in conversation promotes active learning (Soller, 2001), supports complex problem solving (Brown et al, 2002), and facilitates group understanding (Gunawardena et al., 1997). Another strand of research indicates contributions that stimulate controversy in discourse support knowledge generation and meaning making in groups (Gunawardena et al., 1997; Zielger et al., 2013), as well as influence learning outcomes (Webb & Paliscinar, 1996; Soller, 2001; Bouton & Garth, 1983). Some of the limitations of these taxonomies, as they are applied in research, are they tend to relate conversational contributions to evidence of broadly framed outcomes (i.e., meaning-making, collaborative skill) that are very context-specific. Additionally, these taxonomies often cluster similar types of contributions *across* different outcomes, making it difficult to ascertain whether unique relationships exist between specific types of contributions and particular outcomes, however they are framed.

In an attempt to resolve these issues, recent research set out to understand the relationship between types of conversational moves and learning outcomes. In their study of informal learning among executives in small group conversations, Wilson and Hartung (2015) identified five "types" of learning outcomes based on participants' self-reported learnings. Their findings generally align with those presented in Anderson et al.'s (2001) expanded taxonomy of Bloom's learning outcomes that categorize types of "knowledge" into four categories. The first two, factual and conceptual, reflect the "knowing-what" aspects of knowledge. The second two, procedural and metacognitive, reflect the "knowing-how" aspects of knowledge. Mayer (2002) further suggests that these types of knowledge can be stratified into higher and lower level cognitive processes (see Table 2.1, below), and suggests that more complex thinking relates to conceptual and metacognitive types of outcomes.

Table 2.1

Associations between types of knowledge and levels of cognitive processing

Level of Cognitive Process	**Type of Knowledge**	
	"Knowing What"	**"Knowing How"**
Higher	Conceptual	Metacognitive
Lower	Factual	Procedural

Wilson and Hartung (2015) present evidence that most conversations in their sample were "rich" in one type of outcome and that factors such as contribution equality and conversational structure were associated with these outcomes. For instance, participants in conceptually- and reflectively-rich conversations posed many questions, contributed in equal proportions, and attended to the process of learning (e.g. checking in on goals, adjusting the strategy, etc.). In contrast, informational- and operationally-rich conversations were strikingly different. In these conversations, participants were sharing stories of practice or making statements of belief or points of view on a topic. Instead of equal participation, there were one or two speakers who dominated the talking time and there was little, if any, attention to group process.

A subsequent study (Hartung and Wilson, in press) found that a number of specific conversational moves were significantly associated with unique types of learning outcomes. For instance, the three different types of inquiring moves identified in the study were uniquely associated with evidence of different outcomes: questions that asked others to explain their thinking (*Probe*) were associated with operational learning outcomes; those that drew out the perspective of others (*Pose*) were associated with conceptual learning outcomes; and those that asked others to reflect on what they were learning (*Prompt*) were associated with informational learning outcomes. Other findings include that *Point of View* (*POV*) moves (i.e., statements/expressions about what one thinks or believes), *Challenges* (i.e., disagreements about an idea in discussion), and *Puzzles* (i.e., noting what one wonders about or a point of confusion) were associated with evidence of conceptual learning, whereas S*elf-stories* (i.e., sharing a practice or anecdote from personal experience) were associated with evidence of operational learning.

It is important to note two important limitations that make it difficult to generalize these findings to other contexts. The first is that, in this study (informal learning conversations among executives), there were no specified outcomes that participants were tasked with producing, nor was there a problem to be "solved." The second is that the study associated conversational participants' self-reports about what they learned with the conversational moves occurring in the conversation in order to examine "how" participants talked and "what" they talked about (e.g., conceptual things, operational things, informational things, etc.).

Even with these limitations in mind, it is still reasonable that these findings could be extended to consider whether particular conversational moves are associated with particular types of evidentiary outcomes in other learning contexts (e.g., formal, virtual, workplace, etc.). In particular, because in a serious game environment participants are engaged in a specified task situated in a context, the associations of particular types of talk could be examined in relation to a less biased measure, namely evidence of "what" students talked about in their discourse that is evident in the digital records captured through game play. Said another way, discourse data from a serious game environment could be examined to consider whether particular types of conversational behaviors (i.e., syntactic contributions) are uniquely associated with talk "about" different types of things (i.e., semantic contributions). This is an important question that, to my knowledge, has not been empirically studied.

As discussed above, evidence in the literature indicates that there are relationships between conversational contributions in discourse and learning outcomes in learning conversations, broadly defined. However, another area of research considers learning from the more particular perspective of collaborative activity in discourse.

2.2 Collaborative learning and activity

Little consensus exists in the literature regarding how to define "collaborative learning," given the often ambiguous and shifting definitions of the terms *collaboration* and *learning* depending on the context (Dillenbourg, 1999; Lai, 2011). Dillenbourg (1999) describes collaborative learning simply as "a *situation* in which *two or more* people *learn* or attempt to learn something *together*" (p. 1, emphasis original). More specifically, collaborative learning involves mutual engagement, synchronized effort, and the development of a shared understanding and solution to a problem or task. In contrast, cooperative learning characterizes a division of labor to complete a task or solve a problem, with each participant taking responsibility for some portion of the workload, often with separate "solutions" contributed by each participant (Weinberger, 2003; Hamalainen, 2006; Dillenbourg, 1999; Roschelle & Teasley, 1995; Soller et al., 1998).

Kumar (1996) outlines three central theories of learning that guide the processes, outcomes, and study of collaboration, all of which focus on the *interactions* among individuals. The first is socio-constructivist theory. An extension of Piaget's work (1932), this theory focuses on the development of the individual *in relation to* social interaction, but tends to disregard underlying factors that may enhance learning. Studies in this vein compare differences between individual and collaborative learning using pre/post tests.

The second, socio-cultural theory, originates in the application of Vygotsky's (1978) theories related to the zone of proximal development. This theoretical lens is concerned with the individual's development as a function of his/her social interaction. Research in this paradigm is concerned with the causal effect of the independent application of what an individual learns through collaborative activity to a similar task or problem in another situation.

The third theory governing collaborative interaction is socio-cognitive in nature. This perspective posits that individuals develop through interaction with the environment (the physical *and* social context) in which they learn. Therefore, the use of this theory in research is concerned with the social context in which learning happens and its relevance to real-world knowledge and skill acquisition. Said another way, because,

> …knowledge is socially constructed [it is] best supported through collaborations designed so that participants share knowledge and tackle projects that incorporate features of adult teamwork, real-world content, and use of varied information sources (Scardamalia and Berieter, in press, p.2).

Much of the research on collaborative learning in recent decades has been conducted in the computer-supported collaborative learning (CSCL) paradigm[2]. CSCL makes use of technology to develop "intentional" environments that mediate, support, and facilitate group interaction for the purposes of learning and building knowledge collaboratively (Stahl, 2006). This medium has given rise to new methods of studying learning and is particularly salient because,

> …[i]f we conceive of learning as situated in its specific social settings and as a collaborative knowledge-building process in which knowledge artifacts are constructed through interaction among people, then we need to give up the idea that learning can be adequately studied in settings that are divorced from the kinds of situations in which we want the learning to be useful (Stahl, 2008, p. 71-72).

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[2] Another popular paradigm in the literature is known as a "knowledge building environment," which is distinguishable from the CSCL paradigm by virtue of, "its focus on processes of knowledge creation and idea improvement and…its ability to represent the resulting community knowledge" (Scardamalia and Bereiter, 2003, p. 5).

In these environments, student discourse (or "communication activity") plays a central role in how people learn through collaboration. Research in CSCLs has therefore been instrumental in providing a closer analysis about the effects of collaboration on learning through analyzing the mechanisms, characteristics and processes found in social interaction patterns (e.g., social, verbal, text-based, etc.) (Steinkuehler, 2006; Stahl, 2006). In effect, CSCL environments open the "black box" of collaboration to allow for the study of the roles and influences that variables play in collaboration, rather than merely *controlling* for them in studies of collaborative activity (Stahl, 2006; Kumar, 1996; Dillenbourg et al., 1995). Importantly, studies in CSCL have revealed the value of social interaction from the socio-cognitive perspective (Adamson et al., 2014).

Research on factors that influence collaboration and its effects on learning are well documented, though findings vary widely. For instance, early research by Webb (1991) finds that the effects of collaboration are mediated by the content and quality of interaction and discourse (see also Kittleson and Southerland, 2004; Soller et al., 1998). Studies by Blumenfeld et al. (1996) and Rahman et al. (2010) propose that there are particular supports and factors related to achieving particular types of learning outcomes in collaborative interaction, such as group composition, roles, task structure, and participation patterns. More specifically, other research claims that quality of interaction varies positively by the heterogeneity of group composition (Van den Bossche et al., 2006; Webb et al., 1998; Wooley et al., 2010); is influenced by participation style (e.g., leaders/helpers; active/passive) (Richmond and Striley, 1996), gender balance (Bear and Wooley, 2011), and student status (Webb, 1995); and is moderated by the degree to which the task requires collaborative communication (Mercer, 1996).

Other research suggests important factors that affect collaborative outcomes are those that influence the social interaction of the group (Kreijns et al., 2003). In particular, research using conversational analysis to study collaborative learning has identified particular features of interactions that support participants' developing shared knowledge and understanding (Roschelle, 1992; Soller et al., 1998). For instance, Soller et al. (1998) claim that effective collaborative interaction requires more "active learning" skills in discourse (i.e., justifications, elaborations, explanations), whereas cooperative learning relies more on skills such as leadership and trust. Other research highlights factors central to understanding collaborative outcomes, such as participants' prior knowledge and social ties (Hausman, Chi and Roy; 2004; Bluemink et al., 2010), patterns of interaction (Stahl and Hesse, 2006; Dillenbourg, 1999; Wooley et al., 2010), frequency of in-group activity (Schellens and Vackle, 2005; Conejo et al., 2013), and equality of participation and contribution (Storch 2002; 2009; Weinberger and Fischer; 2006; Van den Bossche et al., 2006;). While no consensus has emerged about which factors most influence social interaction and collaborative learning, the literature suggests that a robust study of collaborative interaction should account for a variety of factors.

A different research lens considers the relationship between the personal perspectives of group participants and their learning. For example, Stahl (2006) claims that personal perspectives (i.e., past experience, expectations, meaning structures) influence the building of social knowledge through collaborative learning. Research on group conversational interaction, specifically in game environments, suggests that participants' attitudes, perceptions, and dispositions have a significant impact on players' experience, social interaction, the outcomes of collaboration, as well as on students' performance (Bluemink et al., 2010; Kritzenberger, 2012; Giannakos, 2013; OECD, 2013). Given these findings, it is also reasonable to ask whether engagement in more collaborative interactions effects a change in a student's attitudes and perceptions, a topic that to my knowledge has not been empirically explored in the literature.

Finally, Dillenbourg (1999) suggests that research concerned with the effects of collaborative learning should focus on the specific effects of particular categories of interaction, rather than on the effects of collaborative learning in general. To do so, many researchers have approached the analysis of interactions in discourse using derivations of frameworks such as those developed by Toulmin (1985) or Berkowitz and Gibbs (1979, 1983). However, a recent framework, *Accountable Talk*® (also referred to as *Academically Productive Talk*), is also promising given its current use in educational practice and research, and its grounding in a socio-cultural perspective of learning (Michaels et al., 2008).

2.3 Academically Productive Talk and Collaborative Discourse

Academically Productive Talk (APT) is a content-independent framework of conversational behaviors that emphasizes the importance of social interaction to facilitate accountability to a community of learners, to knowledge, and to accepted standards of reasoning through collaborative discourse (Michaels et al., 2008; Adamson et al. 2013; Resnick et al. 1993). APT codifies a body of conversational behaviors and interactions[3] (i.e., "moves") that 15 years of research show promote reasoned participation, foster effective discourse, provide access to improved knowledge structures, yield increases in academic achievement, and facilitate transfer to other domains (Michaels et al., 2008;

[3] Core moves include: "Say More," "Press for Reasoning," "Revoice," "Restate," "Add More," "Agree/Disagree," "Explain," and "Challenge."

Adamson et al. 2013; Resnick et al. 1993, 2013; Kumar and Rosé, 2011; Rosé et al., 2015). Recent research in CSCL has employed the APT framework to design collaborative "scripts[4]" and "intelligent conversational agents[5]" that confirm and extend prior findings. Studies using such tools report that APT effectively supports collaborative learning (Adamson et al., 2014; Hamalainen, 2006; Weinburger et al., 2005) and yields substantial gains in learning based on pre/post test scores (Chaudhuir et al., 2009; Ai et al., 2010; Kumar et al., 2010).

Of particular interest is Adamson et al.'s (2014) summary of findings from a number of experimental studies employing dynamic APT scripts with conversational agents in high school and undergraduate STEM-focused courses. These studies tested the effects of two facilitative moves, *Revoice* and *Agree/Disagree*, on learning gains and student interactivity. In the experimental conditions the conversational agent, based on the automated evaluation of prior student contributions, inserted these moves into the flow of students' synchronous chat discourse as they solved a CSCL task. The researchers present evidence that suggests that the use of these moves is followed by "pockets of intensive discussion" and yield gains in achievement, though the effects varied by context (i.e., difficulty of the material and age level of students).

For instance, in studies of 9th grade science learners (see Dyke et al., 2013), the *Revoice* move was found to be an effective support for collaborative learning when students engaged with challenging and/or unfamiliar material. In particular, the researchers report a significant and positive correlation between the number of

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[4] Schemas that facilitate collaborative learning and activity.

[5] CSCL interfaces designed to provide interventional (i.e., facilitative) support for students engaged in collaborative tasks/activities such as *Basilica* (see Kumar and Rose, 2011) and more recently, *Bazaar* (see Adamson and Rose, 2012).

"revoicable assertions" contributed by a student and those contributed by their teammates in their discussions, suggesting that the initiation of the *Revoice* move by the conversational agent elicited more substantive and critical interactions between students. These effects were diminished, however, when the CSCL task material was more familiar (i.e., easier) in the same student sample.

Further studies conducted with college freshman found mixed effects (see Adamson et al., 2014). For example, in a CSCL task in an engineering design course using material familiar to students, there was a negative effect on learning outcomes related to the use of the *Revoice* move by the agent. However, a significant and positive correlation in the control condition between the frequency of a student's *unprompted* use of this move in the course of conversation and that of their teammates suggests that the endogenous use of the *Revoice* move by students increased interactivity in students' discourse. The authors conclude that "more advanced learners are already good at articulating their own ideas [and that the *Revoicing* support] is unneeded for them. Rather, they need to be pushed beyond that to connect to the reasoning of their partner students" (ibid, p. 120).

In a fourth study (again with college freshman) the experimental condition centered on the use of the *Agree/Disagre*e move in a chemistry-focused CSCL task. Findings indicated that the use of this move by the agent intensified student interactions and yielded increases in learning. As above, this study also indicated a significant and positive correlation between the number of "revoicable assertions" contributed by a student and those contributed by their teammates in their discussions, indicating that the *Agree/Disagree* intervention "precipitated pockets of intensive discussion."

Although further research is needed to establish the effects of other APT moves in the framework on student discourse, this emerging work is highly promising. Of particular interest is that these initial findings suggest that once an APT move is introduced into student discourse there may be a group level effect on their usage. Said another way, as students introduce collaborative moves in the flow of conversation, as exemplified by APT, there is emerging evidence that a tone may be set within the group for their more frequent use in subsequent interactions. Following from this, it is also reasonable to consider whether more collaborative interactivity during group discourse yields unique types of meaning making and/or characteristically different knowledge structures in a given context, such as is found in games and simulations for learning.

As summarized above, research has established that there are numerous factors that influence social interaction during collaborative activity. Furthermore, research shows that APT effectively supports collaborative social interaction and promotes increased learning gains for individuals. Little is known, however, about the relationship between APT and the learning of, or knowledge structures developed by, groups through discourse in situated social activity. From a socio-cognitive perspective this is an important consideration and implies that the group, not the individual, may be the appropriate unit of analysis in the study of particular types of social interaction on the process, or outcomes, of collaboration (Stahl, 2006; Dillenbourg et al., 1996; Dillenbourg, 1999). This position is further supported in literature that suggests, because a group's discourse is a representation of knowledge in and of itself (i.e., group cognition), it is the "property" of the group and its collective achievement and meaning making, and not merely the sum of each individual's knowledge and contributions to the group's discourse (Clark, 2001; Scardamalia and Bereiter, 2010). By extension, Stahl (2008) further suggests that, if knowledge building is situated in groups, "we can observe the construction and evolution of the knowledge in the artifacts that are produced, in the sentences spoken, sketches drawn, and texts inscribed" (p. 70).

Finally, another question that has yet to be considered is whether the experience of APT in discourse affects an individual's attitudes and perception in relation to the domain of study around which they are engaged in discourse. One way to fill the aforementioned gaps in the literature is to apply the APT framework for analysis in an environment that reflects a socio-cognitive theory of collaborative activity, such as those found in games and simulations.

2.4 Games and simulations for learning

The educative value of simulations has been proven over 40 years of research, but their widespread use and application in educational settings is limited because of issues related to adoption, design and development, sustainability, cost, and innovation (Schank, 2001; Klopfer et al., 2009). There remain vast and sophisticated applications that other disciplines use to improve learning and understanding scarcely imaginable even 10 years ago.

However, as Zapata-Rivera and Bauer (2012) point out,

> …[n]ew technologies, including video games, can play an instrumental role in transforming current educational and assessment practices by facilitating the creation of environments where students can acquire and demonstrate 21st century skills because they support communication, collaborative problem solving and measure conceptual understandings, cognitive processes and skills progressions as students play them" (p. 152).

Scardamalia *et al*. (2012) provide a thorough summary of the many ways in which current technologies can be leveraged to design “richer, deeper, wider ranging learning activities and assessments” (p. 224). For example, they can provide for, or support, authentic and dynamic environments, access to collections of information sources, forms of collaboration, multiple representations of phenomena, and the broad simulation of tools (ibid; USDoEd, 2010)

In particular, the last decade has seen a rise in the development, use, and testing of virtual and simulation-based game environments in educational contexts, sometimes referred to as “serious games,” which can be broadly defined as games with a purpose beyond play that are designed to explicitly educate or train (Shute, Ventura, Bauer and Zapata-Rivera, 2009; Sawyer and Smith, 2008). Such games have received extensive treatment in the literature regarding the ways in which they provide powerful learning environments that can potentially transform educational practices because they can both teach and assess,

> …competencies that we believe are important and that are aspects of thinking highlighted in cognitive research [because they] make visible sequences of actions taken by learners in simulated environments; model complex reasoning tasks; and do it all within the contexts of relevant societal issues and problems that people care about in everyday life (Vendlinski and Stevens, 2002, as cited in USDoEd, 2010, p. 27).

To illustrate, one popular type of serious game is a MUVE (Multi-User Virtual Environment). In MUVEs multiple-player participants:

1) simultaneously access a virtual context (representative of the real-world, or at times a fantastical world) as avatars[6];
2) interact with and use digital representations of real-world artifacts and tools;

[6] graphical or text-based representations of participants

3) interact and communicate with other participants and "agents[7]"; and
4) engage in collaborative activities with other player-participants to solve problems similar to, or representative of, those found in real-world contexts (Ketelhut et al., 2008; Dieterle, 2009).

MUVEs such as Quest Atlantis (atlantis.crlt.indiana.edu) and River City (muve.gse.harvard.edu/rivercityproject/) facilitate inquiry and the development of higher order thinking skills by requiring students to access and apply disciplinary content and conceptual tools to solve complex, socially significant problems such as those encountered by doctors, scientists or mathematicians in an immersive environment (Barab et al., 2011; Ketelhut et al., 2008; Dieterle, 2009; Shute et al., 2009). MUVEs have been designed to engage students in a range of learning activities, including those related to scientific and mathematical concepts and understanding, historical-political situations, computer programming and collaboration, social and moral development, and socially responsive behavior, as well as adult learning in the fields of graduate distance education and in pre- and in-service teacher training and preparation (Dieterle, 2009).

In these game environments, students "experience immersion within a virtual world because of features such as interactive stories that provide context and clear goal structures for problem solving" (Shute et al., 2009). Schank (n.d.) refers to this as a "story-centered curriculum" where students feel connection because it relates to authentic aspects of the world they live in. They are immersed as active agents who play multiple authentic and valuable roles in furthering a narrative as they learn how to *do* something through encountering complex situations that demand the learning and application of

[7] computer simulated personalities

inter-disciplinary knowledge and understanding. As described by Baker *et al*. (2008), immersive environments are attractive because:

> …they can provide the technical means to (a) create a range of task scenarios for students, from well-defined problems with one correct answer to open-ended problems with multiple solutions, all within the same setting; (b) require students to reason while demonstrating their understanding of the content; and (c) respond dynamically to students' interactions with the simulation (Baker and O'Neil, 2002) (p. 7).

Shaffer and Gee (2012) argue that such immersive experiences are good for learning because the games that provide them are built around problem solving and inherently require and assess key deeper learning competencies. By design, they integrate learning and assessment, "introduce complex concepts when they are needed," and keep players engaged and motivated, because they are presented with "a sequence of challenges that gradually increase in difficulty, so players are constantly working at the cutting (and most exciting) edge of their abilities" (ibid, p. 212). Unfortunately, prominent and well-intentioned educational practice perpetuates a disconnect between the kinds of knowledge students learn in school and the kinds of situations in life and work wherein this knowledge may be useful (Mislevy, 2010) - students are too often asked to "use the tools of a discipline" without an understanding of how practitioners use them (Brown et al., 1989).

Broadly speaking, research suggests the affordances that serious games provide can support a better understanding of the relationships between communication activity, collaborative problem solving, and how groups co-construct knowledge and understanding. First, they provide rich environments for observing the knowledge and cognitive processes used in solving complex problems not commonly accessible in classroom environments (Baker et al., 2008; Baker and O'Neil, 2002; Quellmalz and

Pellegrino, 2009). For instance, research from the learning sciences finds that educational outcomes improve when students learn through social interaction with peers and experts (Gee, 2008; Behrens et al., 2008; Bransford et al., 2000). Other research suggests that learning is enhanced when students employ domain-specific tools to solve socially significant problems (Hatano and Oura, 2003) and engage in extensive feedback and revision cycles that support systematic reflection and self-assessment/evaluation (Black and Wiliam, 2004; Quellmalz et al., 2012; Perkins and Salomon, 1989; 1994; Anderson et al., 1996; Bransford and Schwartz, 1999).

More specifically, the research on simulation-based games reveals how the development of expertise and transfer are “triggered” by the affordances of simulated activities. For example, thinking skills and meta-cognitive processing are facilitated by the opportunity to utilize a variety of strategies that the participant possesses. Additionally, because simulation based games delineate degrees of understanding and cognitive demand required to solve the problems of interest in the simulation, they can simultaneously accommodate and reveal alternate/multiple solution strategies that are representative of different levels of expertise of the players (Vendlinksi, et al., 2008; Behrens et al., 2012).

Second, serious games collect nuanced and complex data about student activity in the environment that can be used in analyses of learning (Pellegrino and Quellmalz, 2010; Ketelhut et al., 2008; Dieterle, 2009; Shaffer and Gee, 2012; Behrens et al., 2012). Every action taken in the “problem space” of the game provides information about the nature of student interaction with tools, artifacts, resources, collaborators, etc. These extensive digital records (also referred to as log files, data streams, or click streams) provide highly detailed data that can be used to examine the cognitive and performative aspects about whether and how students solve problems collaboratively, and the ways in which they *learn* how to do so (Vendlinski et al, 2008; Shaffer et al., 2009; USDoEd, 2010; Behrens et al., 2012; Dieterle, 2009; Shaffer et al., 2009; Pellegrino and Quellmalz, 2010).

Finally, serious games enable researchers to examine interaction from the socio-cognitive perspective of knowledge (i.e., cognition is not something that happens "inside" a person) through observing the "coordinated interplay of actions within and among people in a socially-constructed space" (Shaffer, 2004, p. 5). That is, because they replicate complex environments or simulate real-world communities of practice (Lave & Wenger, 1991), games and simulations provide a situated context for applying findings from the learning sciences that suggest cognition is situated and distributed physically, socially, and symbolically in the ways people think, learn and work in the world (Barab et al., 2012; Gee, 2008; Brown et al., 1989; Dieterle, 2009).

This socio-cognitive stance, also referred to as "situated learning," is rooted in a perspective that the knowledge people have and the ways in which they acquire and make meaning of it is socially negotiated, co-constructed, and context specific to particular communities of practice (Vygotsky, 1978; Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Schon, 1983, 1987), as is found in the world of work where people often work to solve specific and task-oriented problems. This stance is a stark contrast to the more common conception of learning that is overly focused on the individual and his/her accumulation of facts and information. However, mounting evidence in the literature suggests that what we think of as "knowledge" is a function of meaning making through social interaction, and that learning with others serves as the foundation upon which individual learning is built (Stahl, 2008).

Unfortunately, there is a persistent disconnect between the kinds of knowledge students learn in school and the kinds of situations in life and work wherein this knowledge may be useful (Mislevy, 2010; Resnick, 1987). For instance, students are too often asked to “use the tools of a discipline” without an understanding of how practitioners use them (Brown et al., 1989). In contrast, there are particular ways that professionals (e.g., scientists, historians, journalists, engineers, etc.) organize domain knowledge, and use tools and resources in the solving of problems. Said another way, there are particular ways that professionals organize knowledge, use tools, and leverage resources. These ways of thinking in, and characteristics of, a discipline are referred to as an epistemology, or an “epistemic frame” (Shaffer, 2004).

2.5 Epistemic frame theory and epistemic games

Shaffer (2004; 2005; 2006) proposes the *Epistemic Frame Theory* to describe the structure of a particular community of practice. The epistemic frame of a community of practice includes five elements that comprise the "grammar" (Gee, 1993; 1999) of how a particular professional culture uniquely operates in the world:

1) Skills (i.e., domain-specific abilities/competencies);
2) Knowledge (i.e., information, concepts);
3) Identity (i.e., social/cultural roles);
4) Values (i.e., opinions/beliefs); and
5) Epistemology (i.e., how claims are justified);

The development of a professional epistemic frame - the ability think and behave like a professional - occurs through making connections among these elements that are emblematic of a particular community (Svarovsky, 2011; Arastoopour & Shaffer, 2013; Chesler et al., 2013; Arastoopour et al., 2014). Using epistemic frame theory and detailed study of real-world practicum, aspects of learning in a discipline are codified to design the structures and activities of an epistemic game: an authentic learning environment that is a computer simulation of a professional workplace that allows young people the opportunity to develop the ability to think and work like a professional (Svarovsky, 2011; Shaffer et al., 2009; Shaffer and Resnick, 1999; Shaffer and Gee, 2012). A number of epistemic games (or "virtual internships") have been designed over the last decade to simulate professional practice in the fields of journalism, urban planning, engineering, and graphic art (Shaffer, 2005; Nash et al., 2012).

Recently, Boots and Strobel (2014) examined the architecture of three epistemic games designed and implemented by EGG/GAPS (*Urban Science*, *Nephrotex*, and *Escher's World*) and found them to be emblematic of Leonard Annetta's (2010) six "I's" for serious educational game design. Their analysis suggests that these games coherently incorporate and scaffold the elements of **I**dentity, **I**mmersion, **I**nteractivity, **I**ncreasing complexity, and **I**nformed teaching to yield a game that is **I**nstructional and educative in nature (i.e., a game that is "serious"). Additionally, epistemic games are designed with the types of "symmetrical" structures that research suggests create effective environments for collaboration (see Dillenbourg, 1999). For instance, students in the simulation have "symmetry of knowledge" in that teams are comprised of students at roughly the same level of knowledge experience in the domain. Further support for knowledge symmetry comes in the form of embedded resources needed to complete the task in the simulated environment (i.e., all students have access to the same knowledge, information, etc.). A second symmetrical structure reflected in epistemic game design is that of student "status" - although there are in-game mentors who provide some facilitation, the majority of the collaborative interaction is within the peer group and not defined by the mentor relationship. Lastly, there is symmetry of goals in that there is a *common* group goal/task that students are working toward, which mediates conflicts that could arise should students be working to also obtain individual ones.

Most importantly, epistemic games provide an authentic, situated experience for learning wherein the ways in which students develop an epistemological identity can be observed. Epistemic games, therefore, are an example of an environment that "inverts" the traditional model of learning that suggests one must first learn *about* something before learning to *be* something. Instead, an epistemic game posits that through learning to *be,* students begin to learn *about* (Thomas and Brown, 2009).

Prior research using data from the epistemic games implemented by EGG/GAPS demonstrate the efficacy of their use in a number of ways. For instance, studies have established that "chat" is a viable method for mentoring (Bagley and Shaffer, 2010) and that teams mirror mentor discourse (Nash and Shaffer, 2010). Additionally, Chesler et al. (2013) present evidence that the virtual internship *Nephrotex* significantly motivated and engaged first year engineering students, and that there were significant increases in the learning of engineering content. The authors conclude that the use of chat-log data in the game can be used to effectively assess the process of learning and the attainment of educational outcomes in relation to ABET criteria. In another study, Arastoopour et al. (2013) report findings that support the proposition that, because *Nephrotex* is a "realistic simulation of the epistemology of the community," it is an effective CSCL environment that can support students' affiliation with the community of practice through engaging the simulation.

Other studies have illuminated relationships between what groups talk about (i.e., the sematic aspects of discourse) and different types of outcomes. For example, studies have found significant and positive effects related to civic engagement (Nash et al., 2012), increases in content learning and engagement (Chesler et al., 2013), and positive associations with the focal community of practice (Hatfield, 2011; Bagley and Shaffer, 2011). Still other studies present evidence that there are relationships between the connections made between different epistemic frame elements in discourse and the development of social identity in terms of depersonalization and attraction, as well as changes in women's views of careers in engineering (Arastoopour et al., 2013; Arastoopour et al., 2012). For instance, in one experimental study, Arastoopour et al. (2012) report that the proportion of women playing *Nephrotex* reporting a positive change in their views of engineering careers was significantly greater than the control group, and that male *and* female students who made more connections between the epistemic elements associated with the skills, knowledge and epistemology of engineering design predicted a positive change in their views of engineering careers. In a subsequent study (see Arastoopour et al., 2014), findings suggested that women showed a statistically significant increase in self-reports of their confidence and commitment to engineering, compared to a control group, and that male *and* female students who reported a positive change in their confidence and commitment to engineering made more connections to the epistemology of engineering design and other aspects of engineering practice.

However, two aspects of epistemic games data have not been empirically explored. The first has to do with whether there is a relationship between *how* groups talk (i.e., the syntactic aspects of social interaction and discourse) and *what* they talk about (i.e., the types of epistemic connections they make in discourse). The second is whether *how* groups talk effects a change in students' attitudes and perceptions with regard to the professional domain they are engaged in through the simulation.

2.6 Summary

In this chapter, I presented a review of scholarship that informed the development of research questions and a research design for this study. In particular, prior research has established that: (1) discourse and social interaction play a central role in how and what people learn in collaborative contexts; and (2) there are a variety of factors that influence the nature and quality of the social interaction, as well as, the process and outcomes of collaboration at the individual and group level (e.g., group composition, participation style, gender balance, interaction patterns, personal perspectives, etc.). This body of scholarship suggests that accounting for these factors in the study of discourse and collaborative interaction is not only important, but is facilitated by using data from a CSCL environment, such as a serious game, because of robust datasets that allow for in-depth analysis of variables in collaborative interaction and discourse.

Prior research has also established that there are relationships between types of conversational contributions in discourse and broadly defined learning outcomes. However, such relationships have not yet been empirically studied in a serious games context, nor in relation to semantically based, discipline-specific outcomes. In particular, because of the affordances provided by these environments (i.e., the ability to observe complex cognitive, social, and performative processes used in solving complex problems), they are rich settings for the examination of discourse data in considering whether particular types of conversational behaviors (i.e., “how” students talk) are associated with and/or influence what students talk “about.”

Relatedly, my review found that APT is a promising and viable framework for studying collaborative interaction because it codifies conversational behaviors found to foster effective discourse, provide access to improved knowledge structures, and support collaborative learning. As noted, however, little is known about the relationship between APT and the learning of *groups* through discourse in situated social activity, which is an important consideration from the socio-cognitive perspective of learning. Serious games enable the examination of interaction from this situated-learning perspective because such games replicate complex environments and immerse students in simulations of real-world communities of practice.

Lastly, research on epistemic games in particular reports that participation in “virtual internships” increases motivation, engagement, and content learning for students. Additionally, studies present evidence that there are relationships between the nature and quality of student discourse and important student-level outcomes such as civic engagement, social identity, and increased confidence and commitment. The extant research using data from epistemic games, however, has not yet considered whether there is a relationship between *how* groups talk (i.e., the syntactic aspects of social interaction and discourse) and: (1) *what* they talk about (i.e., the types of epistemic connections they make in discourse), or (2) a change in students' attitudes and perceptions with regard to the professional domain explored in the simulation.

Taken together, my review suggests that using the APT framework to codify and study collaborative discourse in an epistemic game is a promising approach to examine these relationships. In accord with findings from the literature reviewed in Chapters 1 and 2 presented above, in the next chapter I present my three research questions, their related hypotheses, and the design of research used to address them.

Chapter 3

Research Questions and Study Design

Chapter 1 presented the background, context, and theoretical model that situate this study. Chapter 2 presented a review of the various strands of relevant literature and scholarship that provided the foundation for this study. In this chapter, I first outline the research questions and their related hypotheses that guided the design of this study. Next, I present detail about the data sources, followed by the variables and coding procedures, used in this study. This chapter concludes with the presentation of my data analytic plan.

3.1 Research Questions

In response to (1) the previously discussed research and findings about factors that influence collaborative activity and social interaction, (2) current gaps in the literature, and (3) the opportunity for using an exemplary simulation-based game environment for study, I propose three related research questions to guide this study. These questions, and their associated hypotheses, are presented in Table 3.1, below.

Table 3.1

Research questions and hypotheses

Research Question	**Hypotheses**
RQ1: What, if any, academically productive talk moves are associated with the presence of unique epistemic frame elements in group discourse during design team meetings?	**1:** There are unique patterns of epistemic frame elements (i.e., nodes) associated with different academically productive talk moves.
RQ2: Are there differences in the connections among different epistemic frame elements that groups make in their discourse with respect to *Academically Productive Talk*? What, if any, group-level characteristics are associated with these differences?	**2a:** Groups with higher proportions of *Academically Productive Talk* in their discourse will make connections to more epistemic frame elements in their discourse (i.e., these groups will have larger networks, with a greater *variety* of epistemic frame elements). **2b:** Groups with higher proportions of *Academically Productive Talk* in their discourse will make more connections among epistemic frame elements in their discourse (i.e., these groups will have denser networks, with a greater *number of connections* among epistemic frame elements).
RQ3: Do students have a higher probability of reporting a positive change in their attitudes and perceptions toward engineering when they are in a group, or groups, that engage in higher proportions of *Academically Productive Talk* in their discourse (vs. those in a group, or groups, that engage in lower proportions)? What, if any, individual- and/or group-level characteristics are associated with a positive change in attitudes and perceptions toward engineering?	**3a:** Students in groups with higher proportions of *Academically Productive Talk* in their discourse will show a positive change in their attitudes and perceptions toward engineering. **3b:** Individual and group-level characteristics will affect whether students show positive changes in their attitudes and perceptions toward engineering (i.e., a student's initial attitudes and perceptions toward engineering; a student's prior experience).

3.2 Data Sources

3.2.1 Site/Setting

This study analyzed data collected from the epistemic game for engineering, *Nephrotex*[8], designed and implemented by the *Epistemic Games Group* (EGG) and the *Games and Professional Simulations Research Consortium* (GAPS) at the University of Wisconsin-Madison (http://edgaps.org/gaps/). *Nephrotex* is a virtual internship that simulates professional practice in engineering in order to support undergraduate students' development of an engineering epistemic frame that could lead to increased motivation for students to persist in their commitment to study and practice engineering (Arastoopour et al., 2014). In *Nephrotex*, students take on the role of interns at a fictional biomedical design firm working on a team with 3-4 other interns. In this role, students are tasked with designing, testing, and building an innovative device for production that satisfies a number of competing interests of the company's internal consultants (Arastoopour et al., 2012; Chesler, D'Angelo and Shaffer, 2012; Arastoopour and Shaffer, 2013).

Students engage in a number of different types of activities during their virtual internship (see Appendices A and B), including:

1) conducting individual research using simulation-embedded resources;
2) working with their team in a virtual design space to conduct two design-cycle-test cycles in which they develop and test hypotheses, generate device proposals, and analyze results;
3) receiving and interpreting feedback regarding their device performance; and

[8] See http://edgaps.org/gaps/projects/nephrotex/

4) participating in a final, public presentation of device designs (Chesler et al., 2013; Arastoopour et al., 2014; Nepthrotex, 2014).

Throughout the experience, students interact with an in-game supervisor (via email) and an in-game mentor/advisor (via chat and email) who provide support and guidance.

3.2.2 Participants

The participant sample is drawn from two implementations of the *Nephrotex* virtual internship, summarized in Table 3.2, below.

Table 3.2

Summary of student demographics in the Nephrotex sample (n=273)

	Sample A	**Sample B**	**Combined Sample**
Male	151 (77%)	59 (76%)	210 (77%)
Female	44 (23%)	19 (24%)	63 (23%)
Total	**195**	**78**	**273**
Asian or Pacific Islander	12 (6%)	5 (6%)	17 (6%)
Black	4 (2%)	2 (3%)	6 (2%)
Hispanic	1 (1%)	0 (0%)	1 (0%)
Prefer not respond	2 (1%)	7 (9%)	9 (3%)
Other	3 (2%)	1 (1%)	4 (1%)
White	164 (84%)	61 (78%)	225 (82%)
Mixed/Multiple	9 (5%)	2 (3%)	11 (4%)
Total	**195**	**78**	**273**

The first (Sample A) is from the Fall 2012 term with students of undeclared majors (n=195) enrolled in an introduction to engineering course at a large, public university in the mid-west. The second (Sample B) is from the Spring 2013 term with students in declared engineering majors (n=78) in an advanced course at a large, public university in a mid-Atlantic state. All students in each sample were randomly assigned to groups of 4-5 students for the first design activity cycle (Design Cycle 1) (n=55) and randomly re-assigned to new groups for the second design activity cycle (Design Cycle 1) (n=55). Thus, the total sample includes 273 students organized into 110 unique groups.

The sample includes 210 male (77%) and 225 white (82%) students. While these demographics are skewed toward white males, they reflect enrollment trends in undergraduate engineering courses in the United States in 2012 with a few notable differences. For example, this sample over-represents the national average of white students (66%) while under-representing enrollment for Asian-American (12%) and Hispanic (9%) students (Yoder, 2012).

3.2.3 Data sources

Three data sources, obtained from *EGG/GAPS*, were used as the basis for this study and are described below.

Discourse data

Discourse data was obtained through digital capture of chat-logs during design-team meetings (i.e., text-based utterance data). The data used in this study was drawn from four 30-40 minute long meetings (n=210) where the focal activity is on collaboration, decision making and reflection related to the design problem. The first two meetings occur during the first design activity cycle (Rooms 7 and 9, n=110). In the first meeting (i.e., "Conversation 1"), students are expected to share findings from their independent reviews of the literature and then discuss and rank the five device "attributes" they feel would yield the best device design. In the second meeting of this design cycle (i.e., "Conversation 2") used in my analysis, students shared with their teammates the five device prototypes they each designed and then worked together to decide on the "top 5" devices the team came up with to submit for testing. The second two meetings used in my analysis occurred during the second design activity cycle (Rooms 11 and 14, n=110). In the first meeting in Design Cycle 2 (i.e., "Conversation 3"), students meet for the first time in their new groups to share performance results from their prior teams' devices and then proposed five new devices to test. In the last meeting (i.e., "Conversation 4"), students were expected to come to consensus around the team's best device to be submitted for evaluation. As reference, a summary of all of the focal activities in each "room" in the virtual internship is presented in Appendix A.

Epistemic discourse coding

The coding scheme for engineering epistemic discourse, developed by *EGG/GAPS*, is comprised of twenty codes derived from ABET[9] criteria (2011) and guided by epistemic frame theory for professional practice (see Appendix C). For instance, a student utterance coded as *Epistemology of Data* indicates that there was evidence that she justified a design decision by using data (i.e., graphs, results tables, numerical values, research, etc.) and an utterance coded as *Knowledge of Client* indicates that there was evidence that she made reference to the health, comfort and/or safety of the patient. The scheme was applied to the data using a validated auto-coding process that identifies key words and character strings in each utterance to create a binary code for evidence of all twenty codes (1=present, 0=not present)[10]. Previous validation studies between human coders and the auto-coding system obtained Cohen's kappa coefficients between 0.80 and 0.98 for all categories (Arastoopour et al., 2014).

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[9] Accreditation Board for Engineering and Technology
[10] It is important to note that an utterance can be coded for multiple epistemic codes (i.e., a single utterance can evidence more than one epistemic element).

Pre- and post-survey responses

Students responded to 34 Likert-scale survey questions (see Appendix D) administered before and after the *Nephrotex* simulation. Questions in the survey were drawn from the Pittsburgh Freshman Engineering Attitudes Survey (PFEAS), a scale shown to be internally reliable and structurally valid as a measurement of college freshman attitudes toward engineering (Besterfield-Sacre and Atman, 1994; Hilpert *et al.*, 2009; as cited in Arastoopour et al., 2014). Questions in the survey asked students about their associations with engineering careers, their perspectives and beliefs related to the work, characteristics and proclivities of engineers, and their commitment to pursuing a career in engineering. Based on my review of the literature, I identified six survey items (of 31 answered by students in both the Novice and Advanced samples) for use in my analysis, which will be detailed in the following section.

3.3 Variables and coding procedures

The variables used in my study are summarized in Table 3.3 (below), followed by further detail about the coding procedures used for variable generation.

Table 3.3

Summary and description of variables used in this study

Variable (type)	**Description**
Attributes of Discourse	
Discode_*i*[a]	Code representing each of the 28 unique conversational moves
EFrame_*x*[a]	Code representing each of the 20 possible epistemic frame elements (i.e., outcomes)
*x*_TALK[c] (Continuous)	Proportion of a group's discourse that is comprised of *x* moves (where *x* = APT-Conversational, APT-Facilitative, Declarative, Proposal, Eliciting, Administrative)
x _RANK[b] (Categorical)	0 if a group's *x*_TALK is "low", 1 if "moderately low", 2 if "moderately high", 3 if "high"
Individual-level Variables	
APT_EXPERIENCE*x*[c] (Continuous)	Each student's group's APT_TALK in the first design cycle (*x*=1) and second design cycle (*x*=2)
CONTRIBUTE[c] (Continuous)	Proportion of discourse in each room contributed by each student
MALE[a, c] (Categorical)	1 if student is Male, 0 if Female
NOVICE[a, c] (Categorical)	1 if student or group is in Sample A, 0 if Sample B
Group-level Variables	
EQUALITY[b, c] (Categorical)	0 if group discourse is "low" (i.e., un-balanced), 1 if "moderately low", 2 if "moderately high", 3 if "high" (i.e., balanced)
GENDER_BALANCE[b] (Categorical)	0 if a group's gender composition is all male, 1 if composition includes one female student, 2 if includes two female students, 3 if includes three female students
GRP_MALE[c] (Continuous)	Proportion of group that is Male
GRP_NOVICE[b, c] (Categorical)	1 if group is in Sample A (i.e. Novice), 0 if Sample B (i.e., Advanced)

Variable (type)	Description
Survey-related variables	
PRE_SELFEFF[c] (Continuous)	Score reflecting a student's initial sense of self-efficacy toward engineering
POST_ SELFEFF[c] (Continuous)	Score reflecting a student's final sense of self-efficacy e toward engineering after the internship
CHNG_ SELFEFF[c] (Categorical)	1 if student shows a positive gain sense of self-efficacy toward engineering, 0 if student does not
GRP_ SELFEFF[b, c] (Continuous)	Average score of group members' initial sense of self-efficacy toward engineering
PRE_COMMIT[c] (Continuous)	Score reflecting a student's initial commitment to pursuing a career in engineering
POST_COMMIT[c] (Continuous)	Score reflecting a student's final commitment to pursuing a career in engineering after the internship
CHNG_COMMIT[c] (Categorical)	1 if student shows a positive gain in commitment to pursuing a career in engineering, 0 if student does not
GRP_COMMIT[b, c] (Continuous)	Average score of group members' initial commitment to pursuing a career in engineering
PRE_CONFID[c] (Continuous)	Score reflecting a student's initial sense of confidence as an engineer
POST_CONFID[c] (Continuous)	Score reflecting a student's final sense of confidence as an engineer after the internship
CHNG_CONFID[c] (Categorical)	1 if student shows a positive gain in sense of confidence as an engineer, 0 if student does not
GRP_CONFID[b, c] (Continuous)	Average score of group members' initial sense of confidence as an engineer

[a] variable used in RQ1; [b] variable used in RQ2; [c] variable used in RQ3

3.3.1 Attributes of discourse

I developed a conversational-move coding scheme (see Appendix E) to code the syntactic contributions evident in chat-logs of group discourse during the four aforementioned situated activities in *Nephrotex*. The coding scheme consists of seven functional move categories: *APT-Facilitative (APT-F)*, *APT- Conversational (APT-C), Declarations (DECLARE)*, *Proposals* (*PROPOSE*), *Eliciting (ELICIT)*, *Administrative (ADMIN)*, and *Other*. The first category encompasses the eight conversational moves outlined in the APT framework (Michaels et al., 2008; Adamson et al., 2012). Because the APT schema is designed as a facilitative framework for intervention purposes it was expanded for use in this analysis. Specifically, the second category (*APT-Conversational)* was developed to distinguish between utterances that were facilitative in nature and those that appeared endogenously in student discourse in *Nephrotex*. This category is comprised of a variation of six of the eight facilitative moves designed to account for the unprompted or natural occurrence of APT moves.

While the primary concern of this study has to do with the effects of APT, early exploratory data analysis suggested that merely coding utterances as APT or non-APT could disregard other naturally occurring, and potentially salient, characteristics of discourse found in *Nephrotex*. To account for this, the other five functional categories were included in the coding scheme to identity other types of conversational moves. The bases of these categories were drawn from extant schema, and reflect other aspects of discourse (common in CSCL environments and/or simulation-specific) such as utterances that are about administrative or procedural business (i.e., talk about what students *should* be doing or *have* done), presentations of information/research to the group, questions posed to teammates relevant to the group's task, proposals about solutions or processes, and "behaviors" commonly found in online, synchronous conversations (e.g., repairs, presence/departure comments), as well as off-task comments and small talk.

This coding scheme was applied to the utterance data for each player, in each group, in each conversation (i.e., room), where an utterance is defined as every word included in a single message sent in the chat program[11]. Although each utterance is an independent data point, utterances were coded in the context of the conversation to ensure meaningful interpretation. I recruited and trained an external rater to co-code conversational moves in the data and to test the reliability of the application of the coding scheme to the chat-log data. Using a small sample of the data[12], I trained the rater on the use of the scheme in each conversation to clarify the characteristics of each code, address discrepancies in interpretation, and discuss disagreements. Based on this, the rater and I calibrated and refined our application of the coding scheme, modified code definitions, and when necessary, revisited prior coding to account for new understandings or modifications of the code criteria applied later in the process.

To test for inter-rater reliability the co-rater independently coded a 50% sample of the data not used for calibration/training (n=7844 utterances, from 96 conversations). Using the results of the rater's and my own coding of the data, I calculated and interpreted two inter-rater reliability indices. The first was the percent agreement and the second was Cohen's kappa, which accounts for agreement by chance, to evaluate the reliability of applying the coding scheme to identify a unique

[11] The coding scheme also included a code for "combine with above" used to identify contiguous utterances by individual students, though entered as separate contributions, which were later collapsed into one contribution. This coding was included in the inter-rater reliability testing.
[12] ~12% were drawn from each of the four conversation used in this study (5 novice and 2 advanced).

conversational move for each utterance. I conducted these test at two levels of the data. The first considered the reliability of coding each conversational move in the coding scheme. The second considered the reliability of coding the conversational move at the category level (i.e., APT, Declare, etc.). Summaries of these inter-rater reliability tests are presented in Table 3.4, below.

Table 3.4

Summary of inter-rater reliability statistics (n=7844)

Level of Test	Agreement	Expected Agreement	Kappa	Std. Err.	Z	Prob>Z
Move	85.91%	5.02%	0.85	0.0026	333.96	0
Category	89.56%	15.88%	0.88	0.0047	184.81	0

The percent agreements between the co-rater and myself at the conversational move and conversational move category levels were 85.91% and 89.56%, respectively. The associated Cohen's kappa statistics (*k*) were 0.85 and 0.88, respectively, and indicate a "near perfect" level of agreement (>0.81, see Landis & Koch, 1977)[13] at both levels of reliability testing. A summary of frequency counts for each rater, for each category, is provided in Table F1 (see Appendix F).

Given that the primary focus of this study is related to APT, additional inter-rater reliability tests were conducted to test the reliability of coding each conversational move vs. not (i.e., 1=move, 0=not the move). As summarized in Table F2 (see Appendix F), kappa statistics for each APT move ranged from 0.62 to 1.00, indicating a "substantial" to "near perfect" level of agreement for all APT moves. After establishing reliability for the application of the coding scheme to the data, I proceeded to code the remaining chat-

[13] An additional interpretation of kappa statistics can be taken from Fleiss (1981) who suggests that all kappas above 0.75 are "excellent."

log data.

Using this coded data, I then calculated continuous variables representing the proportional use of each group's discourse at the design cycle and conversation levels attributable to each conversational move category (see Appendix G for summary statistics)[14]. Next, to characterize groups' use of each type of talk in subsequent analysis, I generated categorical variables to rank each group's discourse. Groups were divided into four equally sized groupings (quartiles)[15], based on their proportional use of each type of talk (see Table 3.5, below for descriptive statistics). Groups that used a proportion of talk in the upper quartile were categorized as "high" (3); those that used a proportion in the lower quartile were categorized as "low" (0); groups that were within the interquartile range above or equal to the median were categorized as "moderately high" (2); and groups within the interquartile range below the median were categorized as "moderately low" (1).

[14] Because the focus of this study is on the relationship between the substantive aspects of collaborative discourse and the development of an engineering epistemic frame, utterances coded as conversational moves in the "Other" category (*Enter, Express, Repair, State*) were dropped from the dataset prior to variable generation (18% of utterances). Corollary analysis indicated that there was a near perfect correlation (r=0.99, n=110) between the distribution of each type of talk for groups with and without this category, and their exclusion altered the final distribution of each conversational move in the dataset by, on average, 3.6% (range: 1% - 4%).

[15] Use of quartiles for ranking was justified in two ways. First, I note that the mean and median values are similar, suggesting that the data is, overall, evenly distributed around the means. Secondly, because quartiles are less affected by outliers in the data, they are an effective approach to characterize the overall distribution of the data in my sample for the purposes of this analysis.

Table 3.5

Descriptive statistics of proportional use of conversational move categories (types of talk) at each level of analysis (i.e., segment)

			------------------------- Quantiles ------------------------				
Variable/Segment	**Mean**	**S.D.**	**Min**	**q25**	**Median**	**q75**	**Max**
Academically Productive Talk (APT)							
APT Combined							
Conversation 1	0.47	0.12	0	0.39	0.48	0.55	0.68
Conversation 2	0.44	0.1	0.22	0.38	0.44	0.52	0.63
Conversation 3	0.22	0.11	0	0.15	0.22	0.29	0.48
Conversation 4	0.46	0.14	0.11	0.37	0.47	0.55	0.75
Design Cycle 1	0.46	0.08	0.3	0.4	0.46	0.52	0.58
Design Cycle 2	0.31	0.08	0.09	0.24	0.31	0.37	0.49
Entire Sample	0.38	0.11	0.09	0.31	0.38	0.46	0.58
APT-Conversational (APT-C)							
Conversation 1	0.39	0.11	0	0.33	0.38	0.47	0.6
Conversation 2	0.39	0.1	0.19	0.32	0.38	0.45	0.59
Conversation 3	0.2	0.1	0	0.14	0.19	0.26	0.44
Conversation 4	0.39	0.12	0.11	0.3	0.39	0.46	0.69
Design Cycle 1	0.39	0.07	0.24	0.35	0.39	0.44	0.55
Design Cycle 2	0.26	0.07	0.09	0.21	0.26	0.32	0.44
Entire Sample	0.33	0.1	0.09	0.26	0.33	0.39	0.55
APT-Facilitative (APT-F)							
Conversation 1	0.08	0.04	0	0.05	0.09	0.11	0.19
Conversation 2	0.05	0.03	0	0.03	0.05	0.08	0.12
Conversation 3	0.02	0.02	0	0	0.02	0.04	0.08
Conversation 4	0.07	0.05	0	0.04	0.06	0.11	0.2
Design Cycle 1	0.07	0.03	0.01	0.05	0.06	0.09	0.12
Design Cycle 2	0.04	0.02	0	0.03	0.04	0.06	0.1
Entire Sample	0.05	0.03	0	0.03	0.05	0.07	0.12

Variable/Segment	Mean	S.D.	Min	q25	Median	q75	Max
			------------------------- Quantiles				-------------------------
Other Types of Talk							
Administrative							
Conversation 1	0.1	0.06	0	0.06	0.09	0.14	0.29
Conversation 2	0.11	0.08	0.02	0.06	0.09	0.13	0.33
Conversation 3	0.1	0.08	0	0.05	0.07	0.14	0.31
Conversation 4	0.12	0.12	0	0.04	0.08	0.19	0.67
Design Cycle 1	0.11	0.05	0.02	0.07	0.1	0.13	0.28
Design Cycle 2	0.11	0.07	0.01	0.05	0.09	0.14	0.36
Entire Sample	0.11	0.06	0.01	0.06	0.1	0.13	0.36
Declaration							
Conversation 1	0.22	0.08	0.09	0.15	0.21	0.27	0.5
Conversation 2	0.17	0.06	0.04	0.13	0.17	0.2	0.35
Conversation 3	0.36	0.12	0.1	0.3	0.35	0.42	0.7
Conversation 4	0.24	0.1	0	0.18	0.24	0.31	0.5
Design Cycle 1	0.19	0.05	0.07	0.15	0.19	0.23	0.32
Design Cycle 2	0.32	0.07	0.18	0.29	0.31	0.37	0.51
Entire Sample	0.25	0.09	0.07	0.18	0.24	0.31	0.51
Eliciting							
Conversation 1	0.1	0.04	0	0.08	0.1	0.12	0.19
Conversation 2	0.13	0.04	0.05	0.1	0.13	0.16	0.23
Conversation 3	0.14	0.06	0	0.11	0.14	0.17	0.31
Conversation 4	0.12	0.06	0	0.08	0.11	0.16	0.27
Design Cycle 1	0.12	0.03	0.05	0.1	0.12	0.13	0.18
Design Cycle 2	0.13	0.04	0.06	0.1	0.13	0.16	0.29
Entire Sample	0.12	0.04	0.05	0.1	0.12	0.14	0.29
Proposal							
Conversation 1	0.11	0.08	0.04	0.07	0.1	0.14	0.5
Conversation 2	0.15	0.05	0.08	0.12	0.15	0.18	0.31
Conversation 3	0.18	0.13	0.02	0.12	0.14	0.2	0.8
Conversation 4	0.06	0.05	0	0.03	0.05	0.1	0.16
Design Cycle 1	0.13	0.04	0.06	0.1	0.12	0.16	0.24
Design Cycle 2	0.13	0.06	0.04	0.1	0.12	0.15	0.44
Entire Sample	0.13	0.05	0.04	0.1	0.12	0.15	0.44

3.3.2 Contribution equality

There is no consensus in the literature on best practices to calculate a measure of contribution equality in discourse (i.e., the degree to which discourse is balanced among group members). In this study, group contribution equality (*EQUALITY*) was established using an approach outlined by Weinberger and Fischer (2006) for use in CSCLs to measure "heterogeneity" of participation in discourse. To generate this measure, I first aggregated (i.e., summed) the standard deviation of continuous variables representing the proportion of each group member's contributions in each conversation and in each design cycle. Using this approach, higher aggregate values indicate more "distance" in the quantity of contributions within the group, and can therefore be used to characterize groups with greater or lesser degrees of contribution equality.

Next, in order to characterize groups' degree of contribution equality, I generated categorical variables using the same quartile-based approach described above (see section 3.3.1) (see Table 3.6, below for descriptive statistics). To keep the interpretation of this variable consistent with its conceptual frame (i.e., a high rank represents high contribution equality), quartile associations were reversed because higher aggregate values indicate *less* equality. Groups with aggregate values in the lower quartile were categorized as having "high equality" (3); those with values in the upper quartile were categorized as "low" (0); groups that were within the interquartile range below or equal to the median were categorized as "moderately high" (2); and groups within the interquartile range above the median were categorized as "moderately low" (1).

Therefore, in this study a group with "low" contribution equality characterizes a group that engages in more heterogeneous/un-balanced discourse (i.e., there are 1-2 members who dominate the conversation). Conversely, a group with "high" contribution equality is one that engages in more homogeneous/balanced discourse (i.e., there are no overly dominant participant voices)[16].

Table 3.6

Summary of descriptive statistics of contribution equality at each level of analysis (i.e., segment)

			Quantiles				
Segment	**Mean**	**S.D.**	**Min**	**q25**	**Median**	**q75**	**Max**
Conversation 1	0.10	0.05	0.02	0.07	0.09	0.12	0.26
Conversation 2	0.11	0.04	0.01	0.08	0.10	0.13	0.20
Conversation 3	0.10	0.05	0.00	0.08	0.10	0.12	0.31
Conversation 4	0.11	0.04	0.03	0.08	0.11	0.14	0.20
Design Cycle 1	0.10	0.04	0.03	0.07	0.09	0.13	0.17
Design Cycle 2	0.10	0.04	0.03	0.08	0.1	0.12	0.21
Entire Sample	0.10	0.04	0.03	0.08	0.1	0.12	0.21

3.3.3 Survey Variables

Survey Items

As previously indicated (see section 3.2.3, above), 6 survey items about student's attitudes and perceptions toward engineering were used in my analysis. Five of the twenty-one questions about how students rated[17] their feelings about statements related to the work, personal characteristics and proclivities of engineers were retained:

[16] It is important to note that the degree to which a group's discourse was more or less equally distributed was a function of a group's unique composition and dynamic, and not the result of an intentional design feature of the simulation interface or expectations. Said another way, this variable is not a measure of how effective groups were at fulfilling assigned "roles" in their groups regarding how they should communicate, as can be found in other types of simulations in the CSCL paradigm. Instead, this variable reflects the equality of contribution in group discourse among groups wherein any roles students did play were allowed to be fluid and emergent in the context of the collaborative context (Stahl, 2008).

[17] Likert scale ranging from "strongly disagree" (1) to "strongly agree" (5).

- A degree in engineering will allow me to get a job where I can use my talents and creativity.
- Creative thinking is one of my strengths.
- I am good at designing things.
- I feel confident in my ability to succeed in engineering.
- Someone like me can succeed in an engineering career.

These five items were selected because they related to students' beliefs about what they can do and/or what they are good at, and therefore speak to students' sense of confidence as an engineer. The remaining questions in this bank of items were excluded because they focused more on what students like or enjoy doing, or on the perceived work/activity of engineers (e.g., "Engineers are innovative;" "I enjoy problems that can be solved in different ways"). The sixth item retained for analysis asked students to rate[18] how committed they were to a career in engineering.

Eleven more survey items were excluded from analysis because there was no means to determine the degree of self-concordance in student responses (i.e., whether responses on these items reflect students' personal, inherent beliefs about the reasons to pursue an engineering career, or if they are a function of what students perceive they must do based on external pressures or experience (e.g., family pressures, etc.)) (Koestner, et al., 2002). This subset of items asked students to indicate to what extent they thought a career in engineering was associated with a series of prospects (e.g., high salary, prestige, working on teams, etc.) on a scale ranging from "not at all" (1) to "a

[18] Likert scale ranging from "no commitment" (1) to "fully committed" (8).

great deal" (8). These six survey items were then used to generate variables at the individual and group levels for use in analysis, and are detailed below.

Individual Level Variables

Summary statistics of student pre- and post-survey responses on each of the survey items presented above are presented in Table 3.7, below.

Table 3.7

Summary stats player survey responses on individual items used in variable generation

	Mean		**S.D.**		**Min**		**Max**	
Item	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**
A degree in engineering will allow me to get a job where I can use my talents and creativity.	4.46	4.37	0.59	0.62	3	3	5	5
I feel confident in my ability to succeed in engineering.	4.10	4.13	0.71	0.74	1	1	5	5
Someone like me can succeed in an engineering career.	4.36	4.24	0.59	0.75	3	1	5	5
Creative thinking is one of my strengths.	3.75	3.85	0.77	0.80	2	1	5	5
I am good at designing things.	3.66	3.85	0.75	0.74	2	1	5	5
How committed are you to a career within engineering?	6.36	6.45	1.49	1.71	1	1	8	8

First, I generated two continuous variables for use in analysis. The first (*PRE_CONFID*) is a continuous composite variable representing a student's sense of confidence in their skills and abilities related to the work of engineers prior to the *Nephrotex* internship. This composite was obtained by taking the average of students' responses on the first 5 items detailed in Table 3.7 (above). The second variable (*PRE_COMMIT*) is a continuous variable representing students' response to the survey item that indicated their level of commitment to pursuing a career in engineering prior engaging in the simulation.

Next, I conducted Principal Components Analysis (PCA) to determine if creating a composite variable to summarize each student's confidence and commitment toward engineering before and after the *Nephrotex* simulation was warranted. Analysis of PCA results, displayed in Table 3.8 and Figure 3.1 below, indicated that there was one principal component with an Eigenvalue >1, accounting for 46% of variance in the data.

Table 3.8

PCA summary table (n=272; Rho=1)

Component	Eigenvalue	Difference	Proportion	Cumulative
1	2.78536	1.76344	0.4642	0.4642
2	1.02191	0.294375	0.1703	0.6345
3	0.727539	0.0976563	0.1213	0.7558
4	0.629883	0.167583	0.105	0.8608
5	0.462299	0.0892939	0.077	0.9378
6	0.373005	.	0.0622	1

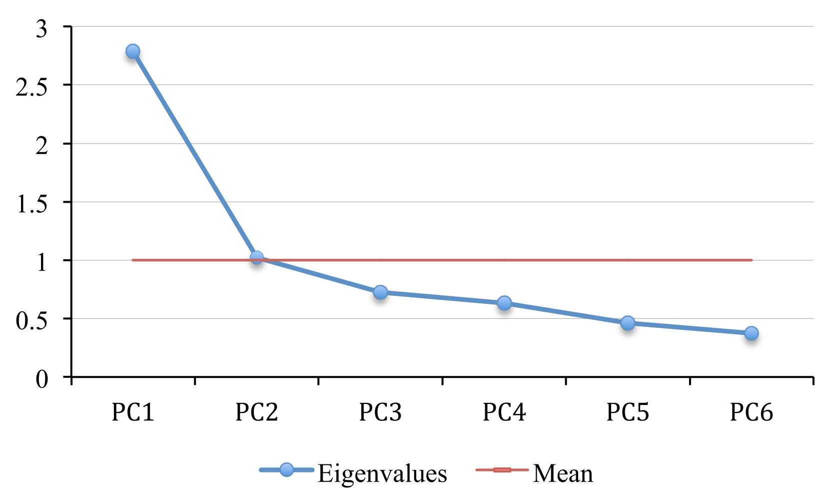

Figure 3.1. Scree plot of eigenvalues after PCA.

The average inter-item correlation (0.35) and Cronbach's alpha (0.77) suggest that there is an acceptable level of internal reliability on this scale, and its first component was retained for use in subsequent analysis. Using the resultant component loadings for PC1, I generated an individual level variable, PRE_SELFEFF, for each player (see Table 3.9, below). A high score on this measure reflects a student's self-efficacy (i.e., their commitment and confidence) related to a career in engineering.

Table 3.9

Summary of component loadings for survey items used in PCA

Item Text	**PC1**	**PC2**
A degree in engineering will allow me to get a job where I can use my talents and creativity.	0.3826	-0.3556
Creative thinking is one of my strengths	0.3776	0.5906
I am good at designing things.	0.384	0.5521
I feel confident in my ability to succeed in engineering.	0.4664	-0.1057
Someone like me can succeed in an engineering career.	0.4584	-0.2207
How committed are you to a career within engineering?	0.3696	-0.4

Finally, Table 3.10, below, summarizes the three individual level variables.

Table 3.10

Summary of descriptive statistics for player-level survey variables in this study

	Mean		**S.D.**		**Min**		**Max**	
Variable	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**
Self-Efficacy (PC1)	0.02	-0.02	1.67	1.90	-6.36	-8.35	3.14	3.14
Confidence	4.08	4.07	0.49	0.53	2.4	1.8	5	5
Commitment	6.40	6.44	1.47	1.71	1	1	8	8

Group level variables

For each group in Design Cycle 1 and Design Cycle 2 I calculated the average of each group member's pre-survey response values for each variable (*PRE_SELFEFF, PRE_COMMIT,* and *PRE_CONFID)* to generate group-level variables to represent each group's collective sense of confidence as engineers (*GRP_CONFID*), level of commitment to pursuing a career in engineering (*GRP_COMMIT*), and overall self-efficacy (*GRP_SELFEFF*) prior to playing *Nephrotex.*

As was done with the other variables described above, I then generated categorical variables to rank each group's average survey measure values. For each variable (*GRP_SELFEFF*, *GRP_COMMIT*, *GRP_CONFID*), groups were divided into four equally sized groupings (quartiles) (see Table 3.11, below, for descriptive statistics). For each of the three survey variables, groups that had scores in the upper quartile were categorized as "high" (3); those that had scores in the lower quartile were categorized as "low" (0); groups with scores within the interquartile range above or equal to the median were categorized as "moderately high" (2); and groups with scores within the interquartile range below the median were categorized as "moderately low" (1).

Table 3.11

Summary of descriptive statistics for group-level survey variables in this study

			----------------- Quantiles -------------------				
Variable/Segment	**Mean**	**S.D.**	**Min**	**q25**	**Median**	**q75**	**Max**
Self-Efficacy (PC1)							
Design Cycle 1	-0.01	0.85	-2.85	-0.64	0.13	0.56	1.82
Design Cycle 2	0.04	0.79	-2.1	-0.46	0.05	0.65	1.37
Confidence							
Design Cycle 1	4.07	0.24	3.32	3.92	4.1	4.2	4.6
Design Cycle 2	4.08	0.23	3.45	3.95	4.08	4.25	4.5
Commitment							
Design Cycle 1	6.36	0.76	4.4	5.8	6.4	7	8
Design Cycle 2	6.37	0.7	5	6	6.25	7	8

Missing Data

A review of the pre-survey data showed a 99.6% (273/274) response rate on the Self-Efficacy and Commitment items identified for use in analysis[19]. A review of the post-survey data indicated that there was a response rate of 87% (239/274) on the Confidence items and 89% (244/274) on the Commitment item. Given that more than 10% of post-survey data were missing, I conducted statistical tests to determine whether any patterns related to student characteristics (e.g., gender, level of experience) or pre-survey response scores were likely to account for the missing data.

First, I conducted t-tests to determine if there were differences in pre-survey scores for students who did and did not complete post-survey items for the Self-Efficacy and Commitment items. Results indicated that there were no significant differences among students who did and did not complete post-survey items on the Confidence items ($t(271) = 0.186$, $p = 0.85$), nor on the Commitment item ($t(271) = 0.320$, $p = 0.75$).

I then calculated Chi-square statistics to determine whether there were systematic differences among students who did not complete the post-survey question items related to the Confidence and Commitment measures, based on gender (i.e., *MALE*) and on level of experience (i.e., *NOVICE*). Regarding gender, the test for the Confidence items was found to be statistically insignificant ($X^2 = 0.81$, $N = 274$, $p = 0.37$), as was the test for the Commitment item ($X^2 = 1.05$, $N = 274$, $p = 0.31$). These results suggest that there were no systematic differences in how male and female students did not respond to these post-survey items.

However, regarding level of experience, the test for the Confidence items was

[19] One student was enrolled in the internship experience, but did not participate, and was therefore dropped from the data set prior to analysis.

significant ($X^2 = 7.58$, N = 274, p=0.006), as was the test for the Commitment item ($X^2 = 7.66$, N = 274, p=0.006). These results suggest that among students who did not respond to these post-survey items, a disproportionate number of novice students did not. I then examined the survey data to see if there were any identifiable, systematic differences in Novice groups that included students who did not respond to post-survey items that could introduce bias in my findings (i.e., students unhappy with their experience in a group, etc.). I found that students with missing data appeared in 19 (48%) of second half Novice groups, with a range of 1-3 players with missing survey data (see Table 3.12, below).

Table 3.12

n (%) of second-half groups that had n players who did not complete all post-survey questions

	1 player	**2 players**	**3 players**	**Total**
Novice (n=40)	12 (33%)	4 (10%)	3 (8%)	19 (48%)
Advanced (n=15)	3 (20%)	--	--	3 (20%)
Total	15 (27%)	4 (7%)	3 (5%)	22 (40%)

Closer examination of how these groups were distributed in the Novice sample showed that, on average, 50% (2.5) of Novice groups in each "cluster" had students with missing data. Table 3.13 (below) summarizes the number of half-two groups (the groups they take the post-survey in) in each "cluster" of groups[20] that have missing data.

[20] Players are organized into "clusters" based on when they engage in the game (i.e. which section of which course they are enrolled in). In the Novice sample, there are 10 organizing clusters (a, b, c,…h) and within each of these clusters there are five groups comprised of 4-5 students (i.e., a1, a2,…a5; b1, b2,…b5; etc.).

Table 3.13

Summary of second half novice groups with missing post-survey data (by cluster)

Group Cluster	n (of 5)
A	3
B	4
C	1
D	4
E	1
F	2
G	2
H	3

This pattern suggests that it was not likely that incomplete post-survey responses were a function of individual students' experience in the internship (i.e., a negative one), which could introduce bias in my results if these responses were not accounted for. Instead, given that most clusters had more than one group, and as many as four, of five that included students with missing post-survey data, I concluded that the systematic differences between Novice and Advanced groups may have had to do with the implementation structure of the simulation and/or groups running out of time as student worked to complete their tasks.

Taken together, my analysis of the missing survey data suggests that removing students with missing cases would not bias my analysis and did not warrant the use of single (i.e., mean substitution) or multiple imputation methods. I therefore concluded that students with missing values on these items could be dropped in the analysis for RQ3.

3.3.4 Gender-balance

On average, groups were 77% (SD=0.19) Male in the sample (n=110), and similarly, 77% in Design Cycle 1 (n=55, SD=0.20) and 78% in Design Cycle 2 (n=55, SD=0.17). Due to variations in group size, the ratio of male to female students in any group varied[21] and I was not able to use a quartile ranking to generate this variable, as described for the variables above. Instead, this variable (*GENDER_BALANCE*) indicates the number of female students (Min=0, median=1, Max=3) in each group. Using this approach, I was able to control for varying levels of gender balance in my analysis (i.e., all male vs. non-all male, etc.). Table 3.14 (below) summarizes the distribution of male and female students in the sample, by group size and gender balance rank. As indicated, thirty percent of groups (n=33) in the sample have no gender balance (i.e., all male), and only 7 groups (6%) in the sample have a majority female composition (no groups are all female).

[21] For instance, a group with 2 female members would be 33% female in a group of 3, 50% in a group of 4, and 40% in a group of 5.

Table 3.14

Summary of distribution of female students (by group size) in the sample of groups, by group size

% Group Female	Gender Balance Indicator 0 (All Male)	1 (1 Female)	2 (2 Female)	3 (3 Female)	Total (%)
Group Size = 3					
33%			1		1 (1%)
Group Size = 4					
50%			4		4 (4%)
25%		7			7 (6%)
0%	4				4 (4%)
Group Size =5					
60%				7	7 (6%)
40%		3	22		25 (23%)
20%		30			30 (27%)
0%	28				28 (25%)
Group Size = 6					
17%		3			3 (3%)
0%	1				1 (1%)
Total	33 (30%)	43 (39%)	27 (25%)	7 (6%)	110

3.4 Data Analytic Plan

3.4.1 Research Question One

What, if any, APT moves are associated with the presence of unique epistemic frame elements in group discourse during design team meetings?

To answer this research question I fit a series of logistic regression models to test the relationship (α-level, $p<.05$) of APT moves, controlling for all other types of conversational moves and individual player characteristics (*NOVICE* and *MALE*), on the probability that evidence of each epistemic outcome would be present in an utterance associated with each move. Models tested these relationships at three levels of analysis (i.e., “segments”) - the sample, design cycle (1 and 2), and conversation level (1, 2, 3, and 4). Final models were determined through likelihood-ratio tests and evaluated for goodness-of-fit. A sample model[22] for this analysis, for each epistemic frame outcome followed this format, where “*EFrame_x”* represents each of the 20 possible epistemic frame outcomes (e.g., *Skill of Data*), and “*Discode_i”* represents each of the unique conversational moves used in my analysis:

$$\log\left[\frac{p(EFrame\_x=1)}{p(EFrame\_x=0)}\right]=\beta_0+\beta_1 NOVICE+\beta_2 MALE+\beta_3 Discode\_1+\beta_4 Discode\_2 \ldots \beta_i Discode\_i+\varepsilon$$

To facilitate meaningful interpretation of results, I then computed and interpreted the average marginal effects (AME)[23] for each conversational move retained in the final logistic models to determine the practical (“real”) effects of each move relative to evidence of each epistemic outcome (i.e., the predicted probability of the evidence occurring based on the discrete change in the presence of the conversational move (i.e., from “0” (not present) to “1” (present)). Said another way, the AME statistic indicates the predicted probability of evidence of the outcome for each predictor variable in a regression model.

3.4.1 Research Question Two

Are there differences in the connections among different epistemic frame elements that groups make in their discourse with respect to APT? What, if any, group-level characteristics are associated with these differences?

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[22] I also tested for interaction effects in all models (*NOVICE*x*MALE*; *NOVICE*x*Discode_i*; *MALE*x*Discode_i*), though none were found to be significant.

[23] Another commonly used statistic to do so is the marginal effects at the means (MEM), or “conditional effects,” which is a statistic of the practical effect of an independent variable in a regression model when all other variables are equal to their means. However, some researchers have argued that the use of AME provides a more realistic estimate of these effects given that the sample means used in the calculations of marginal effects can refer to nonexistent observations in the data in large sample sizes, as are found in this study (Bartus, 2005; Bockarjova & Hazans, 2000).

I answered my second research question by conducting Epistemic Network Analysis (ENA) using a publically available, web-based analytical tool developed by *EGG/GAPS* (http://epistemicgames.org/ena/) to measure the development of complex STEM thinking by quantifying the co-occurrences of epistemic frame elements in discourse (Choi et al., 2010). Arastoopour et al. (2014) provide a concise overview of ENA:

> Because the learning that takes place during a practicum can be characterized by the connections between elements of a professional frame, ENA measures when and how often students make such links during their work. ENA creates a network model (similar mathematically to a social network model) in which the nodes of the network represent the skills, knowledge, identity, values, and epistemology from a domain. The links between these nodes quantify how often a person (or group of people, depending on the model) has made connections between these elements at some point in time. In this way, ENA models the development over time of a student's epistemic frame—and thus quantifies their ability to think and work like professionals (p. 215-16).

Using the ENA tool and the epistemic discourse data, for each conversation (i.e., room), for each group, the co-occurrences of each pair of codes was calculated and used to create epistemic network models for analysis of differences in the associations of particular conversational moves or about different groups' discourse. In what follows, I briefly describe how these visual models are created[24] as well as how they are interpreted.

Network models are graphical projections of the epistemic discourse data in higher-dimensional space based on the singular value decomposition (SVD) of adjacency matrices, which reveal the structure of connections between discourse elements (Orill et al., 2013). To generate these representations, the ENA tool uses a mathematical approach similar to PCA. The tool first creates an adjacency matrix of all possible co-

[24] For a more thorough discussion of the mathematical theories and equations underlying ENA see: Shaffer et al., 2009; Rupp et al., 2009; Rupp et al., 2010; Orill et al., 2013.

occurrences of codes for each group, in each room. These matrices are then converted (i.e., unwrapped) into adjacency vectors and summed for each group. Then, a singular value decomposition (SVD) is conducted on the matrices by rotating the vectors in space to show the greatest variance. In this space, each group's vector containing the code co-occurrences is then represented as a point in high-dimensional space (i.e., ENA space), and can be interpreted by examining the loadings (rotation) matrix for each dimension (Arastoopour et al., 2014). Finally, each network model has a unique "center of mass," derived from its composite score, which is used for significance testing.

Four visual aspects of epistemic network models can be interpreted and compared across models – space/region, size, line weight, and node size (Shaffer, 2014; Arastoopour et al., 2014; Wesley Collier, *Research Assistant* with Epistemic Games Group, personal communication, October 2, 2014).

1) **ENA "Space":** Network models show the relative location of connections made in discourse (i.e., "where" connections are in "ENA space") and elements that are clustered together in space are more "related" than elements further apart in the models. These models are therefore one way of characterizing the nature of epistemic discourse in conversation (i.e., what the "talk" was about).
2) **Network Size:** Network models that are denser, or broader, are those that have more connections to more epistemic elements. This indicates that the connections represented in such models were repeated more frequently, over time, in student discourse. Said another way, it shows whether students repeatedly made connections between more elements.

3) **Line (i.e., Edge) Weight:** The lines connecting any two nodes in a network model indicate the relative strength of the association (i.e., the connection) between those nodes in the model. Stronger line weights (evidenced by color density and thickness) indicate a stronger connection between two nodes relative to other connective lines in the model. Said another way, the strongest connections in a network model are represented by more heavily weighted lines.

4) **Nodes**: A "node" in ENA space represents each epistemic frame element. The location of these nodes remains constant in any network model generated with a given ENA set. The size of the nodes in each model are visual cues about the relative strength of the connections made to that epistemic element because it is proportional to the sum of the strengths of its connections. Said another way, a larger node in a network model, compared to others, can reflect either a) more connections, or b) fewer, though very strong, connections to that node.

In order to compare the richness, density and "location" of connections made in discourse to epistemic frame elements in groups at different ranked uses of APT, I conducted ENA and interpreted results to determine what, if any, differences existed in the types of connections among epistemic elements were made by groups that used differing proportions of APT in their design team meeting discourse by conversation (i.e., room) and design cycle (i.e., over time). Additional analyses were conducted to test whether any group-level characteristics were associated with these differences (e.g., *EQUALITY; GRP_SELFEFF*). Network models were generated and tested using a comparative structure based on the quartile ranking approach described above (see 3.3.1-3). Table 3.15, below, describes the types of comparative variations tested using ENA.

Table 3.15

Summary of structures used to compare groups of differing quartile rankings

Variable Characterization	**Included Rank(s)**		**Variable Characterization**	**Included Rank(s)**
High	3	*vs.*	Low	0
High	3	*vs.*	Non-high	0, 1, & 2
Higher	2 & 3	*vs.*	Lower	0 & 1
Non-low	1, 2 & 3	*vs.*	Low	0

After generating network models, I then used statistical supports embedded in the ENA tool to conduct and interpret t-tests to determine if the observed differences in the relationships between groups' use of APT and epistemic frame elements in the epistemic network models were statistically significant (α-level, $p<.05$) on the x and/or y axes. Additionally, I interpreted Cohen's *d,* which is a statistic used to determine the effect size (i.e., the strength of a phenomenon of interest) of differences, which is the standardized difference between two means[25]. Therefore, the use of this statistic in my analysis represented a measure of the strength of difference in the mean equiload projections comparing any two network models in ENA space.

Finally, because mean network models (the types of models primarily used in this study) tend to have high densities of connections, they can look very similar and differences can be difficult to interpret. Therefore, for those models found to be significantly different, I generated an additional network model – a "subtracted equiload" – to further highlight and reveal differences in the nature of each group's discourse

[25] Cohen's *d* is generated, along with the t-tests, as part of embedded statistical calculations in the ENA tool.

regarding the development of their epistemic frame of professional practice in engineering. To generate these comparative models, the ENA tool "subtracted" the edge weights of one network model from another, one edge at a time. This resulted in a network model with negative values associated with one color and positive values associated with another. This is a visual representation of how any two models were different in terms of the relative strengths of their respective connections.[26]

3.4.3 Research Question Three

Do students have a higher probability of reporting a positive change in their attitudes and perceptions toward engineering when they are in a group, or groups, that engage in higher proportions of academically productive talk in their discourse during design meetings (vs. those in a group, or groups, that engage in lower proportions)? What, if any, individual- and/or group-level characteristics are associated with a positive change in disposition toward engineering?

I answered my third research question using quantitative data from students' survey responses, and qualitative data generated from my analysis of APT use in design meeting discourse. To answer this research question, focused on a positive change in a student's attitudes and perceptions toward engineering after playing *Nephrotex*, I first calculated a continuous variable of the proportion of discourse that was APT for their group in design cycle one (*APT_EXPERIENCE1*) and design cycle two (*APT_EXPERIENCE2*). I then analyzed student's pre- and post-survey responses to identify if there was a positive change in their post-survey scores to generate a code for

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[26] For instance, if two equiload projections (i.e., means of network models) are generated - one red and another blue - when they are "subtracted" in ENA, the blue lines that remain in the model would indicate that those connections were stronger, on average, than in the red equiload model, and visa versa.

each player (*CHNGE_CONFID, CHNGE_SELFEFF, CHNGE_COMMIT*). Finally, I fit a series of logistic regression models to test the significance (α-level, $p<.05$) of participation in groups with higher APT use, controlling for particular individual characteristics (e.g., pre survey scores, level of experience, etc.), and group characteristics (e.g., equality of contribution, gender balance, etc.), on the probability that a positive change in a student's self-efficacy, confidence, and commitment toward engineering would occur. A sample model for this analysis, for each player, followed this format:

$$\log\left[\frac{p(CHNG\_SELFEFF=1}{p(CHNG\_SELFEFF=0}\right]=\beta_0+\beta_1 APT\_EXPERIENCE1+\beta_2 APT\_EXPERIENCE2+\beta_3 PRE\_SELFEFF+\beta_4 NOVICE+\beta_5 EQUALITY+\varepsilon$$

3.5 Summary

In this chapter I presented details about three research questions, their related hypotheses, and the research design that seeks to provide empirical answers to these questions. As indicated, prior to conducting the analyses described above, the first phase of research involved applying, and testing the inter-rater reliability in applying, the conversational coding scheme to the discourse data. Once inter-rater reliability was established, I proceeded with the analytic plan as outlined.

Addressing research questions one and three required the use of logistic regression to determine: (1) what, if any, APT moves are associated with the presence of unique epistemic frame elements in group discourse during design team meeting; and (2) whether students have a higher probability of reporting a positive change in their attitudes and perceptions toward engineering when they are in a group, or groups, that engage in higher proportions of *Academically Productive Talk* in their discourse during design meetings (vs. those in a group, or groups, that engage in lower proportions). Addressing research question two required the use of Epistemic Network Analysis, along with the qualitative review of the discourse data, to determine whether there is a difference in the connections among different epistemic frame elements that groups make in their discourse with respect to *Academically Productive Talk*.

In accord with the research design presented in this chapter, I present the results of data analysis and a discussion for each research question in the subsequent three chapters. I address Research Question 1 (RQ1) in Chapter 4, Research Question 2 (RQ2) in Chapter 5, and Research Question 3 (RQ3) in Chapter 6.

Chapter 4

Research Question One (RQ1)

What, if any, Academically Productive Talk *moves (APT) are associated with the presence of unique epistemic frame elements in group discourse during* Nephrotex *design team meetings?*

4.1 Chapter Overview

As described in Chapter 3, to answer RQ1 I regressed each of the 20 epistemic outcome variables, in each conversation, in each Design Cycle, and in the sample of conversations, on the predictor variables drawn from the coding of discourse that characterized the syntactic contributions (i.e., conversational moves) found in design meeting discourse. As will be presented in this chapter, findings from my analysis suggest that some APT moves are uniquely associated with evidence of different epistemic outcomes in conversational contributions, though findings vary by conversation, type of APT move (i.e., *Facilitative* or *Conversational*), and in the size of practical effect.

First, findings indicated that for epistemic outcomes with a *low* occurrence of evidence in discourse (i.e., those associated with *the Consultant* and *the Client*), APT moves were the sole and/or predominant predictors in regression models. In particular, the APT-Facilitative (APT-F) move *Challenge* (i.e. an utterance that expresses a different conclusion or understanding of something that was said, expressed, proposed, etc.), and the APT-Conversational (APT-C) moves *Share Reasoning* (i.e., an utterance that provided reasoning or justification or clarification about why one thinks, believes, says or claims something), *Add More* (i.e., an utterance that adds to or builds upon something that someone else said, expressed, proposed, etc.), and *Explain* (i.e., an utterance that provides an explanation about why something someone said, expressed, proposed, etc. is right or wrong) consistently predicted such evidence.

Second, for epistemic outcomes that were evident in *moderate* amounts of students' contribution in discourse (i.e., outcomes associated with *Data Analysis*, *Identity*, and the *Skills of Collaboration* and *Professionalism*), APT moves were included among many significantly associated predictors. In these cases, APT moves, relative to other types of conversational moves (i.e., Declarations, Proposals, Eliciting, Administrative), were in some instances stronger, and in other instances weaker, predictors of evidence in utterances of each epistemic outcome.

Third, findings indicated that a number of APT-Facilitative moves (*Revoice*, *Restate*, and *Challenge*) were found to be consistent and strong predictors of epistemic outcomes that occurred in the highest proportions of student contributions during design meeting discourse (i.e., those related to *Engineering Design* and to *Technical Knowledge*). Given the relative *infrequency* of APT-F moves in student discourse (<10%) in the sample of conversations, the prominent practical effects of these moves in relation to these outcomes suggests that the frequency of a type of move is not necessarily indicative of whether or not such a move may be an important and practical type of syntactic contribution relative to an epistemic outcome in student discourse.

Lastly, regardless of the level of occurrence of epistemic outcomes in student's contributions, findings indicated that the APT-Conversational move, *Share Reasoning*, was the most common APT move predictive of such outcomes. This move was often found to have the strongest predicted probability of evidence of outcomes being present in students' conversational contributions across the sample of conversations.

4.2 Chapter Organization

In order to effectively present findings, it is important to characterize the shape and context of the data used in my analysis. Therefore, this chapter is organized as follows. I first present an overview of the logistic regression results and summarize trends in these data. Next, I present a broad summary of trends in the distribution of types of syntactic contributions (i.e., conversational moves) found in the sample of *Nephrotex* design meeting conversations. Following this, in order to organize and provide context for the more detailed presentation of findings, I summarize descriptive statistics regarding the frequency of evidence of epistemic outcomes in student discourse in the sample of conversations, as a proportion of all utterances. I then present key findings about the predicted probabilities (i.e., average marginal effects (AME)) of *Academically Productive Talk* (APT) moves retained in the final logistic models regarding their associations with unique epistemic outcomes. The presentation of these findings are organized in three sections, related to the degree of evidentiary occurrence of epistemic outcomes, namely the degree to which they appear in relatively infrequent (i.e., low), moderate, and high degrees in student discourse. Presenting findings in this way highlights important relationships in the data because even though evidence of some epistemic elements in student discourse may be rare (i.e., references made to *the Client* or *the Consultant*), they still represent central aspects of epistemic discourse. As such, "more" evidence of a particular epistemic type is not an indication of "better" discourse, but rather is a reflection of the general trends in what students attended to in their conversations as they worked on their design problem. Full summary tables of all AME findings can be found in Appendix H. This chapter concludes with a discussion of findings from my analysis of data related to research question one, as well as implications for practice and future research.

4.3 Summary of logistic regression results

Table 4.1, below, summarizes significant findings from logistic regression models regarding the association between APT moves and evidence of epistemic frame elements (outcomes) in student discourse during *Nephrotex* design team meetings. Two features of how data is represented in this table are important to note. Each cell in the table indicates: (1) with which epistemic outcome, if any, each APT move was significantly associated; and if so, (2) in which, conversation(s). For instance, the APT-Facilitative (APT-F) move, *Restate* (i.e., an utterance that prompted someone to repeat something that someone else, or the group, said or decided on), was a significant predictor in two logistic models for Conversation 4, namely, for the outcome *Epistemology of Design* (i.e., evidence in a student utterance that justified decisions using design terms/references), and for the outcome *Knowledge of Design* (i.e., evidence in a student utterance that referred to aspects of the device, prototype, experiment, or filtration membrane). Similarly, the APT-Facilitative move, *Revoice* (i.e., an utterance that reframed what someone said, expressed, proposed, etc. in order to check/clarify understanding), was a significant predictor for the outcome *Skill of Design* (i.e., evidence in a student utterance that conveyed an action related to design development, prioritizing, tradeoffs, and making design decisions) in both Conversation 1 *and* Conversation 4. Second, to more easily recognize patterns of significant associations between APT moves and outcomes, cells in the table are color coded to reflect which epistemic *domain* findings are related to (i.e., Skill (**green**), Knowledge (**orange**), Identity (**purple**), Values (**pink**), and Epistemology (**blue**)). In what follows, I briefly summarize key trends in these data.

Table 4.1

Summary of significant findings of APT moves for each epistemic outcome (cells values indicate which conversation(s) the code was found in; color scheme is organized by epistemic domain)

<table>
<tr><th rowspan="2">Epistemic Element/ Domain</th><th colspan="6">APT-Facilitative (APT-F)</th><th colspan="5">APT-Conversational (APT-C)</th></tr>
<tr><th>Say More</th><th>Press for Reason</th><th>Revoice</th><th>Restate</th><th>Explain</th><th>Challenge</th><th>Say More</th><th>Share Reasoning</th><th>Restate</th><th>Add More</th><th>Explain</th></tr>
<tr><td>Design</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Epistemology</td><td></td><td></td><td></td><td>4</td><td></td><td></td><td></td><td>2 | 3 | 4</td><td>2</td><td></td><td></td></tr>
<tr><td>Knowledge</td><td>1</td><td>1</td><td>1</td><td>4</td><td></td><td>1 | 4</td><td>1</td><td>1 | 2 | 3 | 4</td><td>1 | 4</td><td>1 | 2</td><td>1 | 2</td></tr>
<tr><td>Skill</td><td></td><td>1</td><td>1 | 4</td><td></td><td></td><td>1 | 2</td><td>1</td><td>1 | 2 | 3 | 4</td><td>4</td><td></td><td>1</td></tr>
<tr><td>Data</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Epistemology</td><td></td><td>1</td><td></td><td></td><td></td><td>1</td><td>1</td><td>1 | 4</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Knowledge</td><td></td><td></td><td></td><td></td><td></td><td>1</td><td>1</td><td>1 | 4</td><td>4</td><td></td><td>1 | 4</td></tr>
<tr><td>Skill</td><td></td><td></td><td></td><td></td><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Client</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Epistemology</td><td></td><td>3</td><td></td><td></td><td></td><td>3</td><td></td><td>2 | 3</td><td></td><td></td><td></td></tr>
<tr><td>Knowledge</td><td></td><td></td><td>1</td><td></td><td>1</td><td>1 | 3</td><td>1</td><td>1 | 2 | 3</td><td>1</td><td>1 | 3</td><td>1 | 3</td></tr>
<tr><td>Values</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Consultant</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Epistemology</td><td></td><td></td><td></td><td></td><td></td><td></td><td>1</td><td>1 | 2 | 3 | 4</td><td></td><td></td><td></td></tr>
<tr><td>Values</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>3 | 4</td><td></td><td>3</td><td></td></tr>
<tr><td>Engineer</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Identity</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>3</td><td></td><td></td><td></td></tr>
<tr><td>Intern</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Identity</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>4</td><td></td><td></td><td></td></tr>
<tr><td>Collaboration</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Skill</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>2 | 3</td><td></td><td></td><td></td></tr>
<tr><td>Professionalism</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Skill</td><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td>3</td><td></td><td>3</td><td></td></tr>
</table>

<table>
<tr><th rowspan="2">Epistemic Element/ Domain</th><th colspan="6">APT-Facilitative (APT-F)</th><th colspan="5">APT-Conversational (APT-C)</th></tr>
<tr><th>Say More</th><th>Press for Reason</th><th>Revoice</th><th>Restate</th><th>Explain</th><th>Challenge</th><th>Say More</th><th>Share Reasoning</th><th>Restate</th><th>Add More</th><th>Explain</th></tr>
<tr><td>Attributes*</td><td>1</td><td>1</td><td>1 | 4</td><td></td><td></td><td>1 | 2 | 3 | 4</td><td></td><td>1 | 2 | 3 | 4</td><td>1 | 3 | 4</td><td>1 | 2 | 4</td><td>1 | 2 | 3 | 4</td></tr>
<tr><td>CNT*</td><td></td><td>2</td><td>1 | 2</td><td></td><td></td><td>1 | 2</td><td>1 | 2</td><td>1 | 2</td><td>2</td><td>1 | 2 | 4</td><td>1 | 2</td></tr>
<tr><td>Manufacturing*</td><td></td><td>2</td><td>2</td><td></td><td></td><td>2</td><td>2 | 3</td><td>2 | 3</td><td>2 | 3 | 4</td><td>2</td><td>2</td></tr>
<tr><td>Materials*</td><td></td><td></td><td>2</td><td></td><td></td><td></td><td>2</td><td>2 | 3</td><td>2 | 3 | 4</td><td></td><td></td></tr>
<tr><td>Surfactant*</td><td>1 | 2</td><td>2</td><td>1 | 2 | 3</td><td></td><td></td><td>1 | 2</td><td>1 | 2</td><td>1 | 2 | 3</td><td>1 | 2 | 3 | 4</td><td>2 |3</td><td>2 | 3</td></tr>
</table>

* These elements are keyed to the "Knowledge" domain, though related to aspects of device-specific "technical" knowledge in the internship.

A review of these findings indicates a number of trends that are worth noting. Firstly, epistemic outcomes in the *Knowledge* domain (i.e., of *Design, Data, Client, and Technical Knowledge*) include the most diverse range, and highest occurrence, of predictive APT moves in the sample of conversations. Secondly, the epistemic element of *Design* includes the broadest frequency of significant APT moves across the representative domains of *Epistemology*, *Knowledge*, and *Skill*. Finally, there was a higher preponderance of APT moves from the Conversational category (APT-C), compared to those in the Facilitative category (APT-F), significantly associated with epistemic outcomes. On the one hand, this is not surprising given that, as a proportion of all utterances, APT-C moves were almost six times more prominent than APT-F moves in the sample of conversations (35% vs. 6%). On the other hand, the fact that so many of the APT-F moves *were* found to be significant predictors of epistemic outcomes related to *Design, Data*, the *Client*, and *Technical Knowledge*, suggests that even with a lower frequency of occurrence, such moves are still an important syntactic aspect of epistemic discourse.

There are also a number of trends in the data regarding the distribution of particular APT moves. For instance, findings highlight that there is a prominent move in each of the APT categories. In particular, among APT-Conversational (APT-C) moves, *Share Reasoning* (i.e., an utterance that provided reasoning or justification or clarification about why one thinks, believes, says or claims something) was a significant predictor of all but two epistemic outcomes (18 of 20), and was found to be so in anywhere from one, to all four, conversations. Among the APT-Facilitative (APT-F) moves, *Challenge* (i.e. an utterance that expressed a different conclusion or understanding of something that was said, expressed, proposed, etc.) was a significant predictor of over half (11 of 20) of the epistemic outcomes in at least one conversation. Of additional interest is that with the exception of APT-F *Restate* and *Explain*, all of the APT moves were associated with epistemic outcomes related to Technical Knowledge (i.e., *Attributes, CNT, Manufacturing, Materials,* and *Surfactant*). As will be presented in detail below, while this appears to be a robust finding, it is mediated by the fact that these moves were significantly associated along with many other types of moves (i.e., Declarations, Eliciting, Proposals, Administrative) in discourse. This suggests that although these moves seem to play a key role in discourse, they are not unique in their associations, with a few exceptions.

Finally, the fact that the APT-C *Share Reasoning* was found to be a significant predictor in so many logistic models related to outcomes in the domain of Epistemology (i.e., *Design*, *Data*, the *Client*, and the *Consultant*) is not particularly surprising given that evidence of these outcomes in student discourse relates to *justifying decisions* (i.e., using design terms/references, data, or reference to the client's and consultant's needs/interests). However, the prominence of this move as a predictor of other epistemic elements suggests that it is an important type of syntactic contribution in other regards, as will be featured in the sections below.

Other trends relate to limited findings from logistic regression. For instance, only three APT moves (APT-F: *Press for Reasoning;* APT-C: *Share Reasoning* and *Add More*) were associated with evidence of the skills of *Collaboration* and *Professionalism*. In fact, very few conversational moves of any type were predictive of these outcomes, suggesting that evidence of these skills in student discourse is perhaps unrelated to "how" people talked, regardless of the type of contribution. More specifically, no facilitative moves (APT-F) were found to be associated with evidence of the *Consultant*, *Identity* (as an Engineer; as an Intern), or the skill of *Collaboration* in student discourse in the sample of conversations. Additionally, results indicated that the *Say More* move (in both APT-F and APT-C), as well as most APT-F moves, with few exceptions, were found to be significant predictors in only one conversation (in particular, in Conversation 1). This suggests that the effects of these moves may, in part, be a reflection of groups' initial efforts to establish how they would engage in discourse as they wrestled with the task in their first collaborative meeting.

4.4 Distribution of types of conversational moves in the sample of conversations

Figure 4.1, below, displays the distribution of conversational moves in the sample of design meeting conversations in *Nephrotex* used in this study. As indicated, APT moves (in purple) overall, and APT-Conversational (APT-C, in red) moves specifically, account for the highest proportion of conversational moves in each conversation. The exception to this is in Conversation 3, when conversational moves categorized as Declarations (i.e., *Present, Point of View (POV), Activity, Inform)* represent the highest proportion of moves (in green). Conversational moves characterized as Administrative (i.e., *State, Pose, Action*) (in grey) and APT-Facilitative (in blue) in nature are the least frequent types of contributions across the conversations (<10%). As will be presented below, low frequency moves are found to be significantly associated with epistemic outcomes as much, and in some cases more so, than moves more frequently found in discourse. A summary table of descriptive statistics of conversational move distribution is presented in Appendix G.

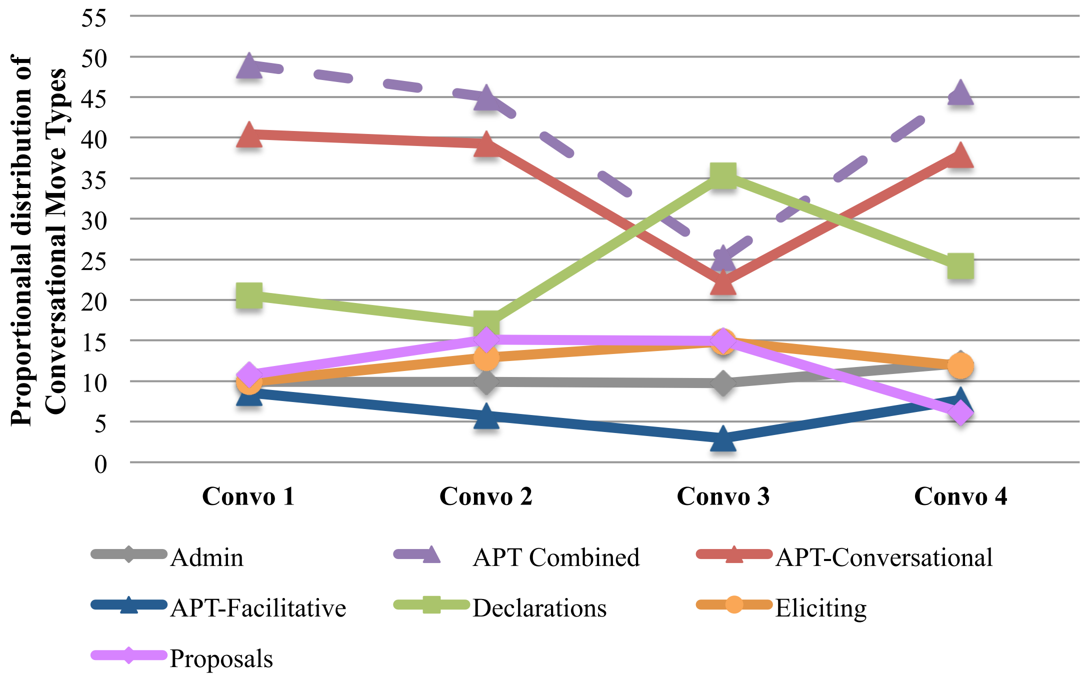

*Figure 4.1***.** Distribution (%) of conversational moves in the sample, by category of move and conversation.

4.5 Trends in evidentiary occurrence of epistemic outcomes in design meeting conversations

Table 4.2 (below) summarizes the distribution of the occurrence of evidence for each epistemic frame element (outcome) in students' design meeting discourse contributions in *Nephrotex* at the sample, design cycle, and conversation levels of analysis. As displayed, 60% of utterances in the sample yielded evidence of engineering epistemic discourse. This trend was, overall, consistent in each conversation with the exception of Conversation 3 (in Design Cycle 2), where 68% of utterances yielded such evidence. Closer analysis of these data shows that the frequency of evidence for different epistemic outcomes in student discourse varied, and can be roughly organized into evidence that occurred in low, moderate, and high amounts in student contributions, and is presented in what follows.

Table 4.2

Summary statistics of distribution of epistemic coding in the utterance data in Nephrotex (N = total utterances in data in segment)

	Sample (N=15068)		**Design Cycle 1 (N=8704)**						**Design Cycle 2 (N= 6364)**					
			Convo 1 (N=4048)		**Convo 2** (N=4620)		**Cycle Total**		**Convo 3** (N=4263)		**Convo 4** (N=2101)		**Cycle Total**	
Epistemic Domain/ *Element*	**n**	**Percent**[a]	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**
No Evidence	5949	39.48%	1683	41.58%	1985	42.00%	3668	42.14%	1381	32.40%	900	42.84%	2281	35.84%
Epistemology	**1975**	**13.11%**	**479**	**11.73%**	**584**	**12.64%**	**1063**	**12.21%**	**578**	**13.55%**	**334**	**15.90%**	**912**	**14.33%**
Client	155	1.03%	126	3.09%	9	0.19%	135	1.55%	12	0.28%	8	0.38%	20	0.31%
Consultant	217	1.44%	47	1.15%	88	1.90%	135	1.55%	43	1.01%	39	1.86%	82	1.29%
Data	223	1.48%	36	0.88%	52	1.13%	88	1.01%	91	2.13%	44	2.09%	135	2.12%
Design	1380	9.16%	270	6.61%	435	9.42%	705	8.10%	432	10.13%	243	11.57%	675	10.61%
Identity	**358**	**2.38%**	**51**	**1.25%**	**77**	**1.66%**	**128**	**1.47%**	**177**	**4.15%**	**53**	**2.52%**	**230**	**3.61%**
Engineer	333	2.21%	40	0.98%	74	1.60%	114	1.31%	171	4.01%	48	2.28%	219	3.44%
Intern	25	0.17%	11	0.27%	3	0.06%	14	0.16%	6	0.14%	5	0.24%	11	0.17%
Knowledge	**13394**	**88.88%**	**3259**	**79.81%**	**4000**	**86.57%**	**7259**	**83.42%**	**4487**	**105.26%**	**1648**	**78.44%**	**6135**	**96.40%**
Attributes	4046	26.85%	1662	40.70%	700	15.15%	2362	27.14%	1158	27.16%	526	25.04%	1684	26.46%
Client	329	2.18%	274	6.71%	21	0.45%	295	3.39%	22	0.52%	12	0.57%	34	0.53%
CNT	984	6.53%	180	4.41%	401	8.68%	581	6.68%	325	7.62%	78	3.71%	403	6.33%
Data	626	4.15%	122	2.99%	119	2.58%	241	2.77%	231	5.42%	154	7.33%	385	6.05%
Design	3726	24.73%	679	16.63%	1187	25.69%	1866	21.44%	1207	28.31%	653	31.08%	1860	29.23%
Manufacturing	1013	6.72%	90	2.20%	565	12.23%	655	7.53%	285	6.69%	73	3.47%	358	5.63%
Materials	1152	7.65%	73	1.79%	153	3.31%	226	2.60%	829	19.45%	97	4.62%	926	14.55%
Surfactant	1518	10.07%	179	4.38%	854	18.48%	1033	11.87%	430	10.09%	55	2.62%	485	7.62%

	Sample (N=15068)		Design Cycle 1 (N=8704)						Design Cycle 2 (N= 6364)					
			Convo 1 (N=4048)		**Convo 2** (N=4620)		**Cycle Total**		**Convo 3** (N=4263)		**Convo 4** (N=2101)		**Cycle Total**	
Epistemic Domain/ *Element*	**n**	**Percent**[a]	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**
Skill	**3433**	**22.78%**	**695**	**17.01%**	**1018**	**22.05%**	**1713**	**19.68%**	**1207**	**28.31%**	**513**	**24.41%**	**1720**	**27.03%**
Collaboration	426	2.83%	43	1.05%	64	1.39%	107	1.23%	254	5.96%	65	3.09%	319	5.01%
Data	400	2.65%	92	2.25%	84	1.82%	176	2.02%	143	3.35%	81	3.86%	224	3.52%
Design	2223	14.75%	438	10.72%	751	16.26%	1189	13.66%	699	16.40%	335	15.94%	1034	16.25%
Professionalism	384	2.55%	122	2.99%	119	2.58%	241	2.77%	111	2.60%	32	1.52%	143	2.25%
Values	**161**	**1.07%**	**94**	**2.30%**	**32**	**0.69%**	**126**	**1.45%**	**20**	**0.47%**	**15**	**0.71%**	**35**	**0.55%**
Client	78	0.52%	67	1.64%	8	0.17%	75	0.86%	3	0.07%	0	0.00%	3	0.05%
Consultant	83	0.55%	27	0.66%	24	0.52%	51	0.59%	17	0.40%	15	0.71%	32	0.50%
Totals[b]	**19321**	**n/a**	**4578**	**n/a**	**5711**	**n/a**	**10289**	**n/a**	**6469**	**n/a**	**2563**	**n/a**	**9032**	**n/a**

[a] Reflects the proportion of utterances coded for the epistemic element in the segment. [b] Totals exceed the segment N's because utterances can be coded for evidence of >1 epistemic frame element (i.e., co-occuring).

4.5.1 Trends for epistemic elements with a low frequency of evidentiary occurrence

Student contributions in *Nephrotex* discourse that included evidence related to *the Client* (Epistemology, Values, and Knowledge) and *the Consultant* (Epistemology and Values) occurred relatively infrequently, as a proportion of all utterances. With a few exceptions, such evidence was present in < 2% of student contributions in each design meeting. As displayed in Figure 4.2 (below), there was slight variation in the degree to which consultants' needs and interests were used to justify design decisions (i.e., Epistemology), and overall, this element is more prominent than others. This trend makes sense and reflects the stage of decision-making in the second meeting of each design cycle, which is focused on submitting new devices for testing. Evidence of references to *the Client* (Knowledge and Epistemology) and *Consultants'* values in student contributions was similar and consistent, after a higher degree of reference in the first design meeting. Relatedly, evidence of reference to consultants' values remains relatively constant regarding the degree to which students include them in their design thinking.

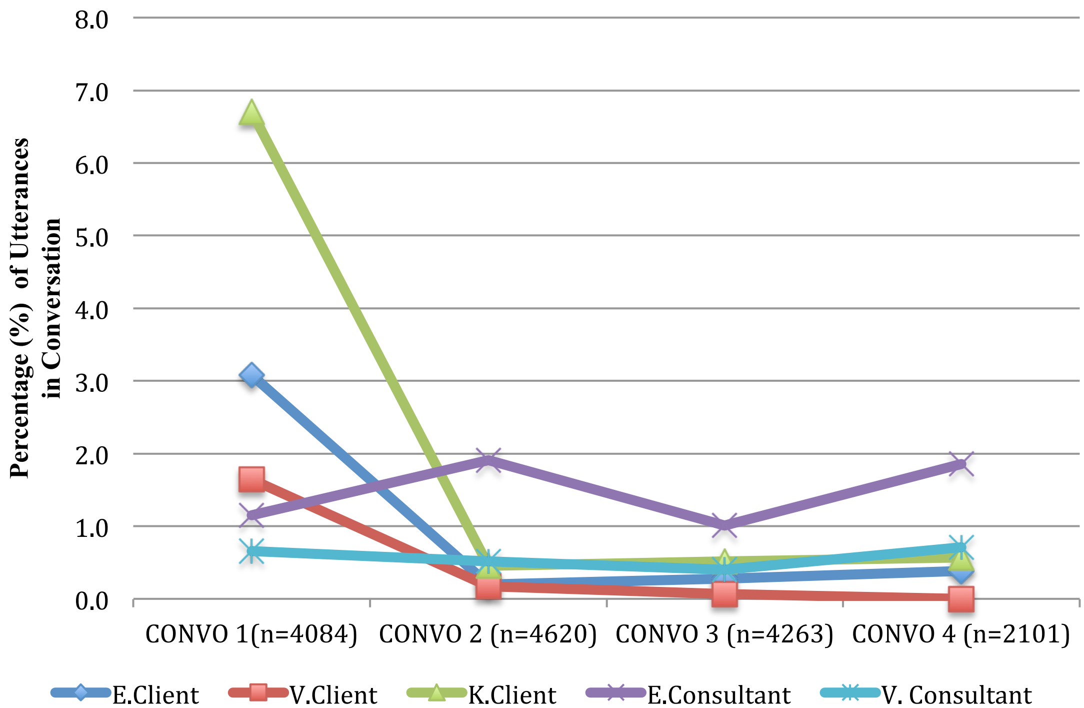

*Figure 4.2***.** Trends in low occurrence epistemic evidence in Conversations 1-4.

4.5.2 Trends for epistemic elements with a moderate frequency of evidentiary occurrence

Epistemic evidence in student discourse that occurred at a moderate frequency included references to aspects of: (1) *Data Analysis* (Epistemology, Knowledge, and Skill); (2) students' *Identity* (as interns and as engineers); and to (3) students' *Professional* and *Collaborative Skills*. First, evidence of all aspects of *Data Analysis* were found in 2% to 7% of utterances, depending on the conversation, and overall, increased in frequency over the course of the internship (see Figure 4.3a, below). This indicates that students tended to incorporate *Data Analysis* into their design thinking more in the second design cycle, relative to other types of epistemic evidence. The exception to this is a slight decrease from the first (i.e., Conversation 1) to the second (i.e., Conversation 2) design meeting. The most marked of these differences is in the frequency of indications that students included *knowledge* of Data in their design thinking. More specifically, on average, references to the *Knowledge of Data* are 1.6 times that of the *Skill of Data*, and 3 times that of the *Epistemology of Data*.

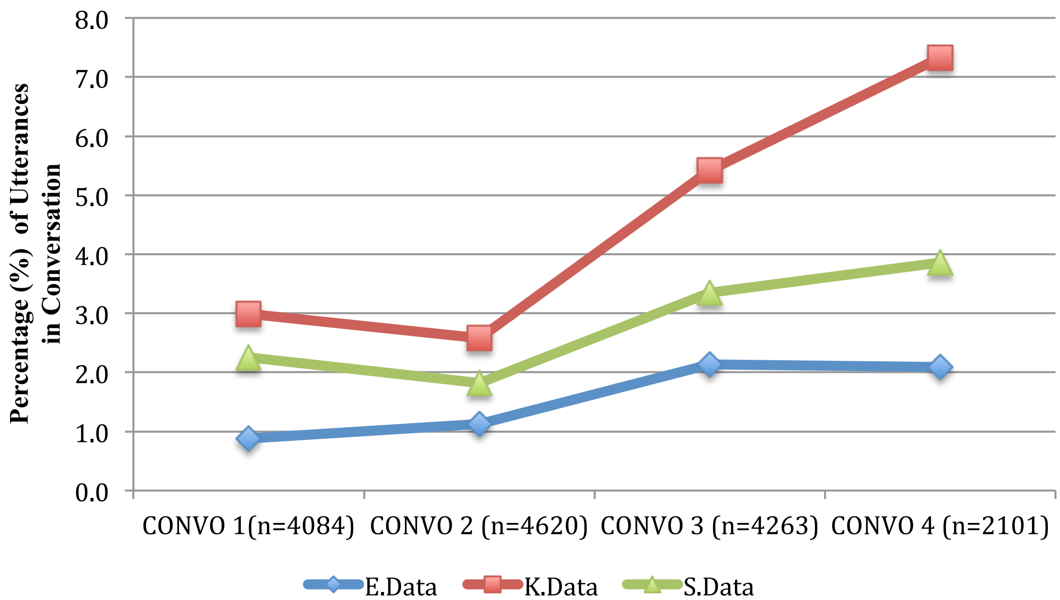

*Figure 4.3a***.** Trends in moderate occurrence epistemic evidence in Conversations 1-4.

Second, the evidentiary trends related to students' *Identity* as interns and as engineers, and their *Skills of Collaboration* and *Professionalism*, are combined and presented below (Figure 4.3b). Overall, evidence in discourse related to students' Identity ranged from ~1% to 4%, and reference to collaborative and professional skill was evident in from ~1% to 6% of utterances in design meeting discourse. More specifically, evidence that students' design thinking incorporated reference to their identities as engineers and collaborative skill increased in frequency in the second design cycle and peaked in Conversation 3. This trend makes sense and reflects the design of the simulation in that it would be expected that as students engage in the collaborative work and practice of engineers, they would come to see themselves more as engineers. References to students' identity as an intern remained relatively low, though consistent, throughout their design meetings. Finally, although representing only a small proportion of evidence in discourse, contributions that included evidence of students' professional skill decreased by 50% (3% to 1.5%) over the course of the internship. This finding can be explained in two ways. First, it is possible that evidence of students' professional skill was reflected in other aspects of the simulation (i.e., in student's personal notebook entries) not examined in this study. Relatedly, it is possible that because the focus of this study was on discourse in design meetings, evidence of collaborative skill would by default be more evident than professional skill.

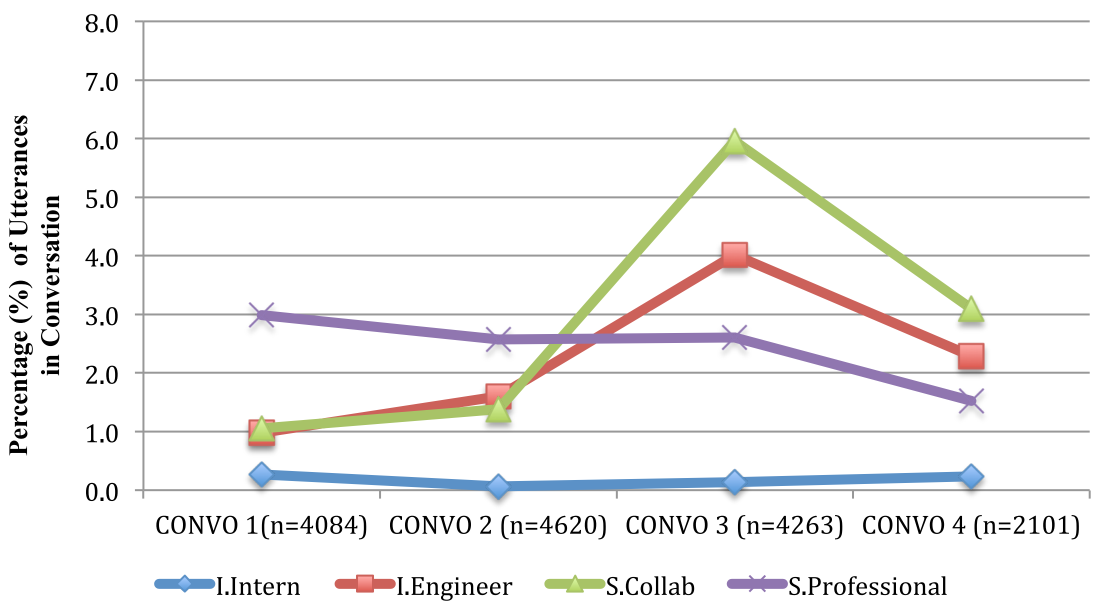

*Figure 4.3b***.** Trends in moderate occurrence epistemic evidence in Conversations 1-4.

4.5.3 Trends for epistemic elements with a high frequency of evidentiary occurrence

Finally, epistemic elements with a high frequency of evidentiary occurrence in *Nephrotex* design meeting discourse, as a proportion of all utterances, are those related to aspects of: (1) *Engineering Design* (Epistemology, Knowledge, and Skill); and (2) device-specific *"technical" Knowledge*. First, evidence in discourse of reference to engineering *Design* elements ranged from 5% to 31%. As displayed in Figure 4.4a, below, the differences in the frequency of evidence in the three design domains (Epistemology, Knowledge, and Skill) were relatively consistent across the four design meeting conversations. On average, references in contributions to engineering *Design Knowledge* were 1.7 times that of the design skill, and 2.7 times that of the *Design Epistemology*. Additionally, while evidence related to design skill plateaus after a slight increase from Conversation 1, evidence of *Knowledge* and *Epistemology of Engineering Design* in student contributions almost doubled in frequency over the course of design meetings (17% - 31% and 7% - 12%, respectively).

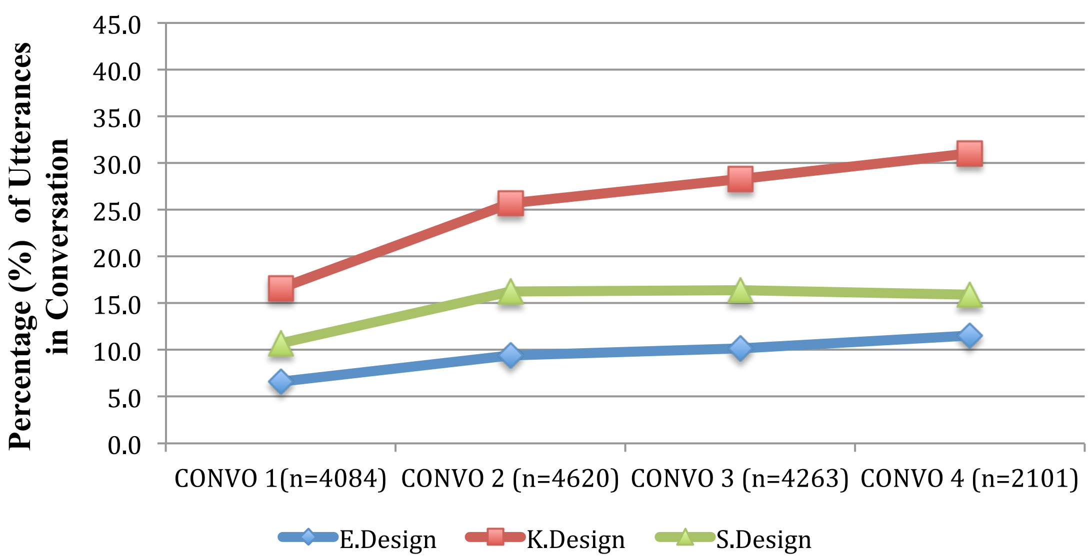

*Figure 4.4a***.** Trends in high occurrence epistemic evidence in Conversations 1-4.

Lastly, evidence of *Technical Knowledge* related the device design (around which the internship in focused) was also found in a high proportion of student contributions, ranging from 2% to 40%, with an average of 11% of contributions in each conversation. As can be seen in Figure 4.4b (below), contributions that include this evidence vary from meeting to meeting. Also evident is that evidence related to knowledge of device “attributes” was most prominent overall, especially in the first conversation. These trends makes sense given that the technical aspects of the device, particularly “attributes,” were a central aspect of what was tested in the FEEDS system for any submitted device.

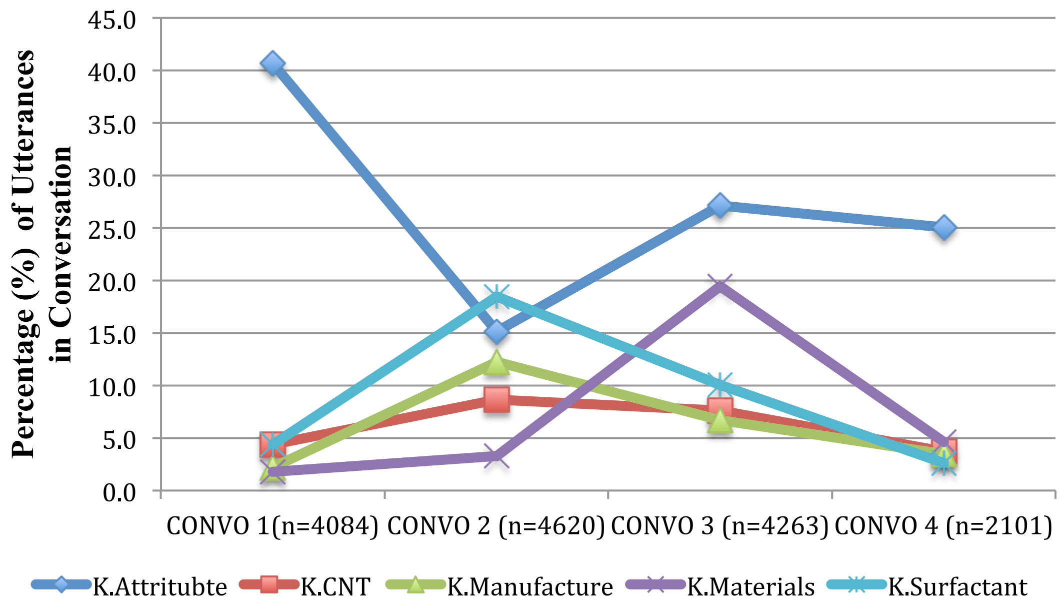

*Figure 4.4b***.** Trends in high occurrence epistemic evidence in Conversations 1-4.

4.6 Average marginal effects (i.e., practical effects) of APT moves in design meeting discourse

In the previous sections I first broadly summarized findings from logistic regression regarding the association of APT moves with epistemic outcomes. I then summarized trends in evidentiary occurrence of epistemic outcomes in student design meeting discourse. In the following sections I present key findings about the average marginal effects (AME) of *Academically Productive Talk* (APT) moves regarding their associations with each of the epistemic outcomes, in each design meeting conversation. AME findings are organized and presented with respect to evidence of epistemic elements in discourse with a low, moderate, and high occurrence of evidence, as presented above. In the figures associated with findings presented below, each featured conversational move is color-coded, based on which conversational move category it is associated with: **red** markers indicate APT moves; **black** markers indicate Declaration moves; **orange** markers indicate Administrative moves; **green** markers indicate Eliciting moves; and **blue** markers indicate Proposal moves.

4.6.1 Effects of APT moves related to epistemic outcomes with low evidentiary occurrence in student contributions

As presented above, evidence of epistemic outcomes related to *the Client* and *the Consultant* occurred relatively infrequently in student discourse (on average, < 2% of utterances). Analysis of logistic regression results indicated that overall, APT moves were the most prominent and strongest predictors of epistemic outcomes in discourse related to such outcomes. As will be described in what follows, AME results suggest that some APT moves have important, practical effects with regard to whether evidence related to *the Client* and *the Consultant* was found in student contributions.

The Client

First, I present evidence indicating that, with regard to outcomes related to *the Client*, four APT moves consistently predicted such evidence: the APT-F move *Challenge* (i.e. an utterance that expresses different conclusion or understanding of something that was said, expressed, proposed, etc.), and the APT-C moves *Share Reasoning*, *Add More* (i.e., an utterance that adds to or builds upon something that someone else said, expressed, proposed, etc.), and *Explain* (i.e., an utterance that provides an explanation about why something someone said, expressed, proposed, etc. is right or wrong).

Knowledge of Client. In Conversation 1, half of *all* types of conversational moves (14/28) were predictive of this outcome (i.e., reference to the health, comfort, and/or safety of the client/patient), including those in the categories of APT, Declarations, Elicitations and Proposals. However, the preponderance of APT moves, seven of which (4 APT-C and 3 APT-F) were stronger predictors than moves of other talk types, suggests that there is an important relationship between such moves and reference to knowledge of the client in this conversation (see Figure 4.5, below). In particular, the predicted probability (PPr) that evidence of this outcome would be present in a student's contribution during design meeting discourse ranged from 0.222 for the APT-C move, *Say More* (i.e. an utterance that explained or elaborated on one's own thinking), to 0.339 for the APT-F move, *Explain* (i.e., an utterance that prompted someone else to explain why something someone said, expressed, proposed, etc. is right or wrong).

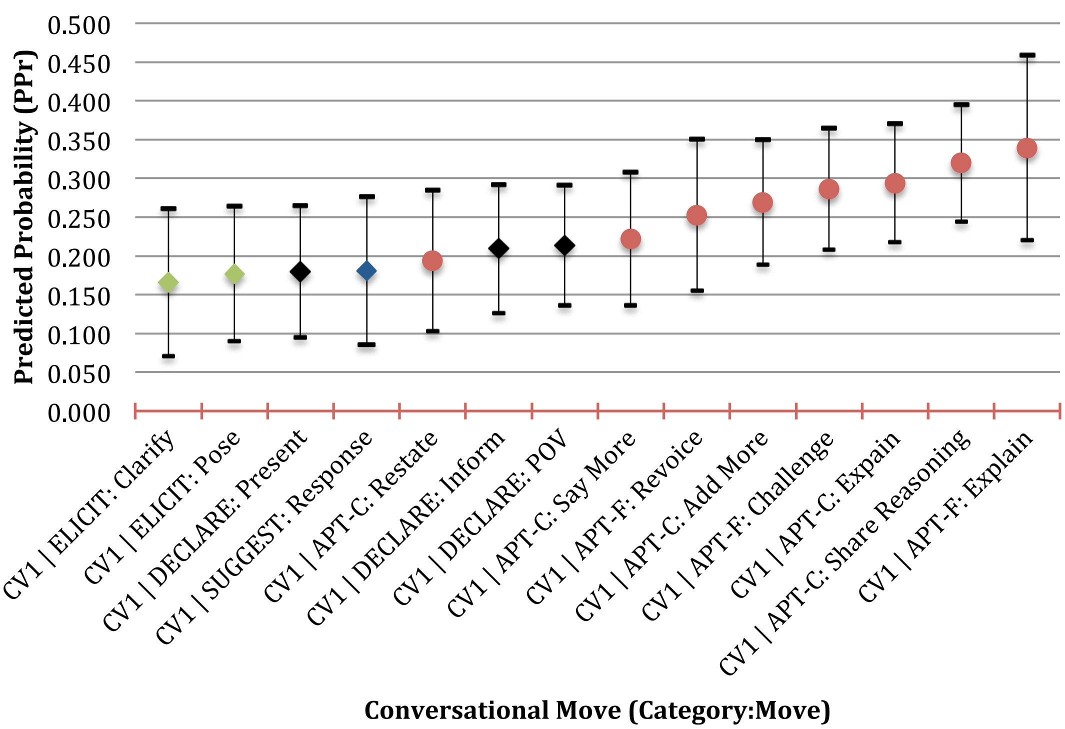

*Figure 4.5***.** AME results associated with evidence of *Knowledge of Client* in Conversation 1.

Of additional interest is that in Conversations 2 and 3, APT moves were *the only* types of conversational moves predictive of whether evidence of the *Knowledge of Client* would be included in a student contribution (see Figure 4.6, below).

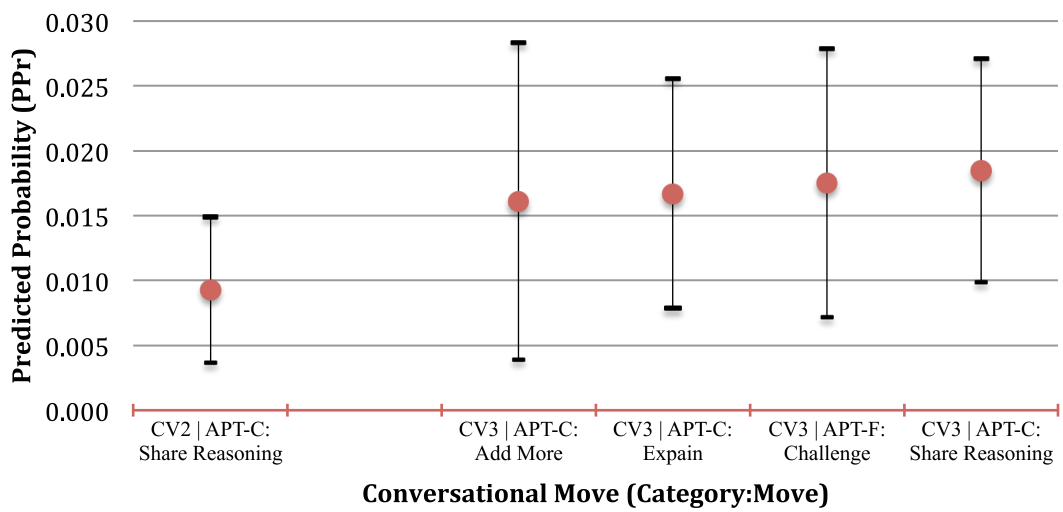

Figure 4.6. AME results associated with evidence of *Knowledge of Client* in Conversations 2 & 3.

In particular, the APT-C move *Share Reasoning* had the strongest average marginal effect on the probability that the associated utterance also included evidence of client knowledge in both of these conversations (0.009 in conversation 2, and 0.018 in conversation 3). Additionally, the average marginal effects of APT-C: *Add More*, APT-C: *Explain* and APT-F: *Challenge* in Conversation 3 are the same or indistiguishable from APT-C: *Share Reasoning,* suggesting that they contribute in more or less equal ways to yielding evidence of this outcome. It is important to note, however, that although these conversational moves are unique in their associations with this outcome in these conversations, the practical effects of these moves were much smaller compared to those found in Conversation 1.

Epistemology of Client. The next client-related outcome pertains to the epistemic domain of Epistemology (i.e., at utterance that refers to the client's or patient's safety, health, wellbeing, or comfort to justify design decisions). For this outcome, the patterns of significant association were most clear when looking at findings at the design cycle level rather than the convesation level. Findings indicate that APT moves were *the only* types of conversational moves predictive of whether evidence of the epistemology of the client would be included in a student's contribution (see Figure 4.7, below).

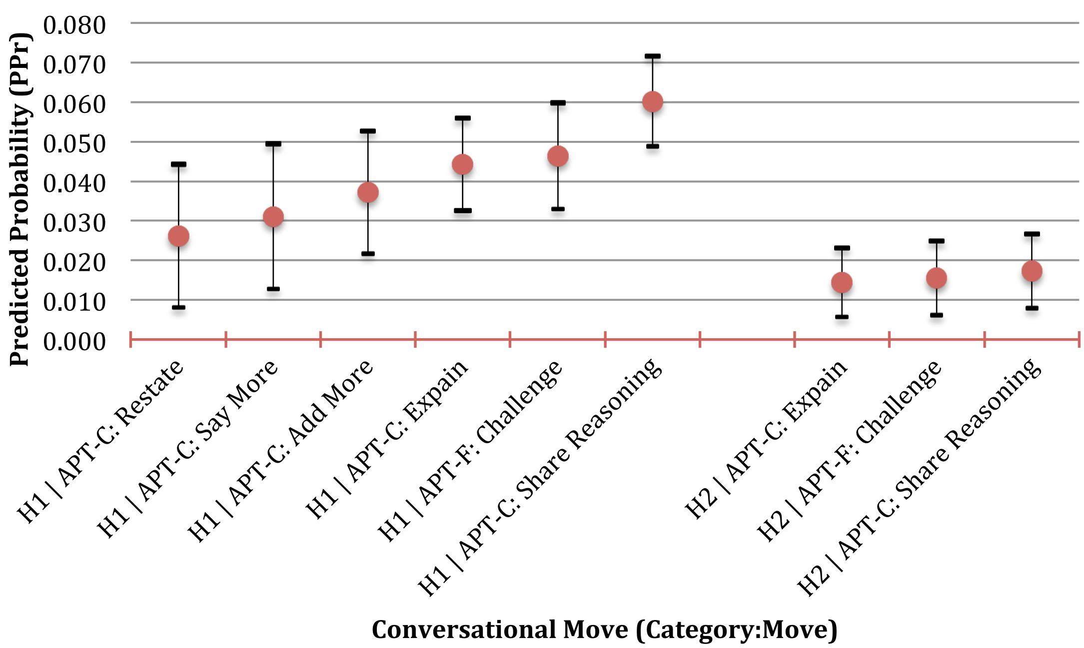

*Figure 4.7***.** AME results associated with evidence of *Epistemology of Client*.

As displayed, three APT moves were found to be associated with this outcome in both Design Cycle 1 (i.e., "H1") and Design Cylce 2 (i.e., "H2") - APT-C: *Explain*, APT-F: *Challenge*, and APT-C: *Share Reasoning* – through their respective predicted probabilities were three to four times stonger in Design Cycle 1. These findings suggest that, relative to all other types of conversational contributions, there is a unique and practical, albeit small, association between students' use these APT moves and evidence of epistemology of the client in conversational contribtions. Additionally, findings suggest that these moves are more predictive of this outcome in design meeting discourse during the first Design Cycle.

Values of Client. Evidence in student contributions in discourse that reflect this outcome make reference to the importance of considering the needs of the client/patient in their design thinking. As was the case with the previous outcome, the patterns of significant associations were most clear when looking at findings at the design cycle level. Results indicated that four APT moves were the *sole predictors* (i.e., no other conversational moves, of any type, were statistically significant) of whether evidence of valuing the client would be present in conversational contributions across conversations in Design Cycle 1 (i.e., Conversation 1 and 2). In particular, the average marginal effects of these APT moves – all of which are small - on the probability of this outcome are displayed in Figure 4.8 (below), and include the APT-C moves *Explain*, *Add More*, and *Share Reasoning*, as well as the APT-F move, *Challenge*. This finding suggests that there is a unique and practical association between students' use these APT moves and evidence of valuing the client's needs in conversational contribtions in Design Cycle 1.

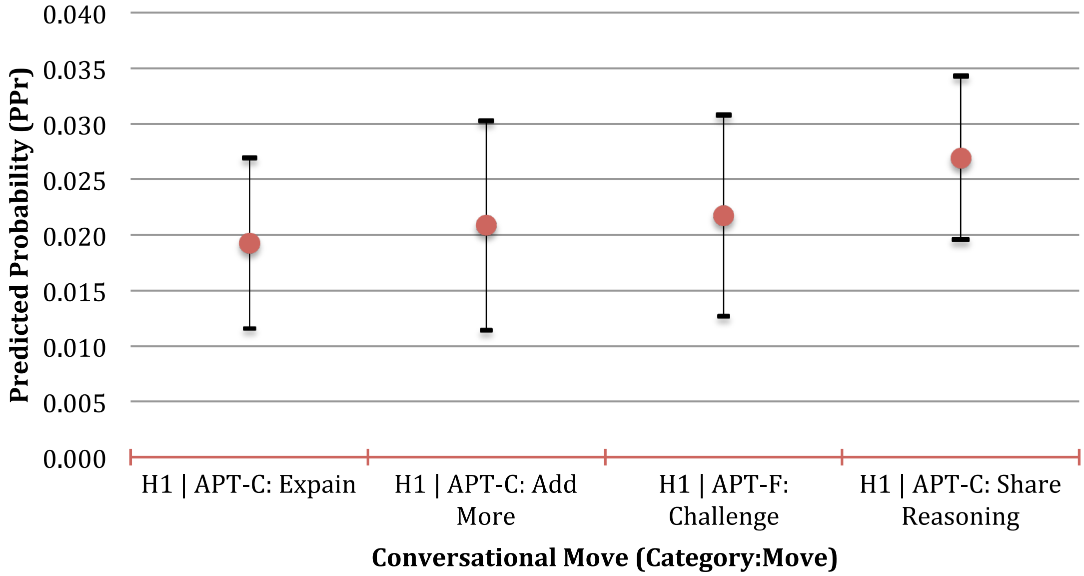

*Figure 4.8***.** AME results associated with evidence of *Values of Client*.

The Consultant

Next, I present findings from my analysis of the average marginal effects of conversational moves associated with epistemic outcomes related to *the Consultant*. These outcomes include evidence in design meeting discourse that students, (1) recognized the importance of considering their internal consultants' needs (i.e., Values), and (2) referred to the internal consultant's needs, wants, etc. as justification for design decisions (i.e. Epistemology). As will be described below, evidence indicates that only 7 of 28 conversational moves (of any type) were associated with Consultant-related outcomes, three of which were APT moves: APT-C *Share Reasoning* and *Add More*, and the APT-F move, *Press for Reasoning*. In particular, in all of these models the APT-C move, *Share Reasoning*, was found to have a practical effect on the probability of such outcomes. Overall, the practical effects of APT moves are less substantial than those reported above for the *Client*-related outcomes.

Epistemology of Consultant. With the exception of the Declaration move, *Present*, in Conversation 1, the *only* types of conversation moves found to be significantly associated with evidence of epistemology of the consultant were APT moves (Figure 4.9, below).

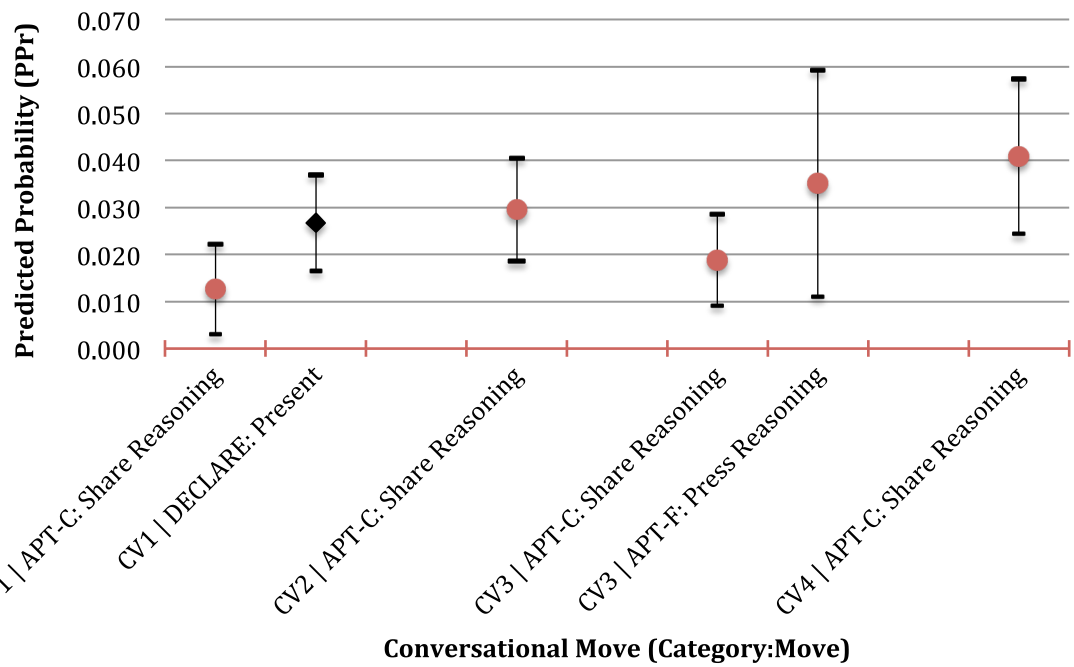

Figure 4.9. AME results associated with evidence of *Epistemology of Consultant*.

In particular, APT-C: *Share Reasoning* was significant in all conversations, with predicted probabilities of an utterance providing evidence of this outcome ranging from 0.013 - 0.041. Addtionally, the average marginal effect of APT-F: *Press for Reasoning* (i.e., an utterance that prompted someone else to provide reasoning or justification about why he/she thinks, believes, says or claims something) on the probability that the associated uterance included evidence of epistemology of the consultant in Conversation 3 was 0.035. Although the practical effects of these moves are relatively small (PPr's <0.05), these findings indicate a unique association between the use of these APT moves and evidence of the epistemology of the consultant being present in a student's contribution.

Values of Consultant. With regard to this outcome, no conversational moves *of any type* were found to be significant predictors of this outcome in conversations 1 or 2 (i.e., Design Cycle 1). In other words, instances when evidence in a student's contribution included the valuing of the consultant's needs/interests were not associated with any particular type of conversational contribution. However, as displayed in Figure 4.10 (below), results did indicate that two APT moves were significantly associated with evidence of valuing *the Consultant* in Design Cycle 2. In particular, in Conversation 3, the *only* predictors were the APT-C moves *Share Reasoning* and *Add More*, suggesting a unique syntactic association with the inclusion of this outcome. The average marginal effects of these moves on the probability of evidence of consultants' values in students' contributions were both 0.01.

In Conversation 4, APT-C: *Share Reasoning* was the only APT move found to have a significant effect, though it had the lowest predicted probability of the four moves significantly associated with this outcome. This suggests that it was more probable that a student's proposal about how the group should proceed with their task (i.e., PROPOSE: *Process*), questions to others about how the group should proceed (i.e., ELICIT: *Process*), and proposing a skills-based strategy related to completing their task (i.e., PROPOSE: *Approach*) were better predictors of whether they would include reference to the need to value the Consultant's interests.

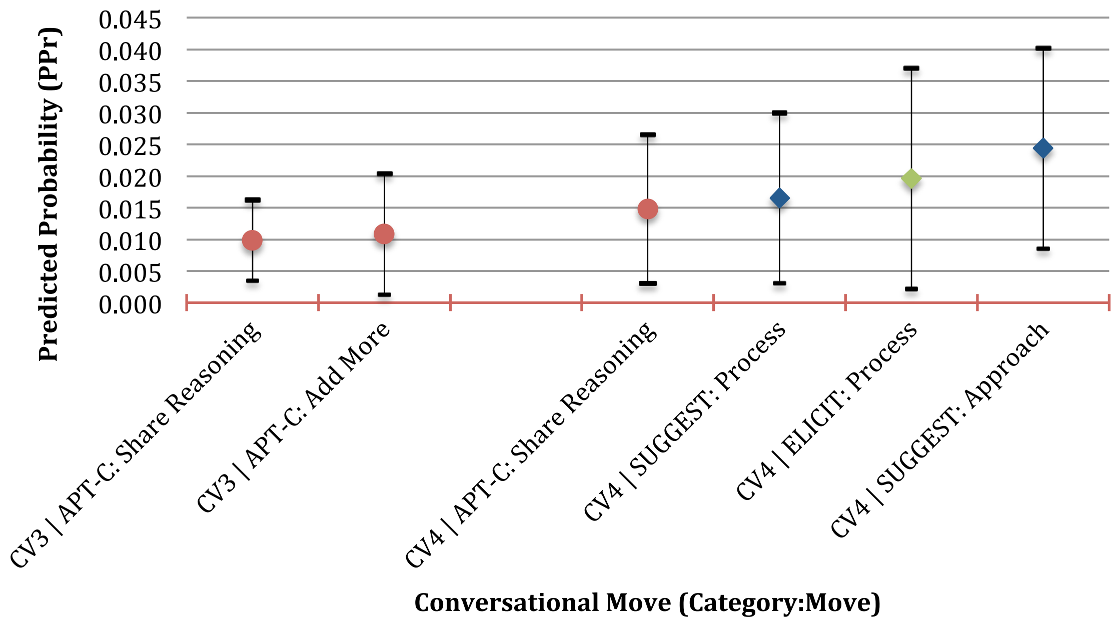

Figure 4.10. AME results associated with evidence of *Values of Consultant*.

4.6.2 Effects of APT moves related to epistemic outcomes with moderate evidentiary occurrence in student contributions

In the preceding section, I presented findings about the AME of APT moves in relation to epistemic outcomes that occurred *infrequently* in *Nephrotex* design meeting discourse. In this section, I present an analysis of AME findings with regard to epistemic outcomes that occurred at more *moderate* levels in student discourse. As previously noted, such evidence is related to student contributions that included aspects of: (1) *Data Analysis* (Epistemology, Knowledge, and Skill); (2) students' *Identity* (as interns and as engineers); and (3) students' *Professional* and *Collaborative Skills*.

Data Analysis

First, I present findings related to data analysis, evidence of which was found in anywhere from 2% to 7% of utterances in design meeting discourse. The most common outcome for the epistemic element of data was students' incorporating their *Knowledge* of data in their design thinking (i.e. references to numerical values, results tables, graphs, or research papers). This was followed in frequency by evidence of students' *Skill* with data (i.e., using/applying their knowledge of data), and lastly, students' use of data to justify design decisions (i.e., *Epistemology*). Analysis of logistic regression results indicated that although many APT moves were significant predictors of such outcomes, they are not unique as was found with the outcomes discussed above (i.e., *the Client*). In other words, when APT moves were found to be significantly associated with epistemic outcomes related to data analysis, they were found to be so among conversational moves of other types (i.e., Proposals, Declarations, Eliciting, Administrative), and often, with smaller predicted probabilites. A brief summary of these findings for the epistemic element data in the domains of *Knowledge*, *Epistemology*, and *Skill* are presented below.

Knowledge of Data. Findings indicated that some APT moves were significantly associated with evidence of this outcome in the first and fourth design meetings (see Figure 4.11, below), though not as strongly as other types of conversational contributions. In particular, four APT moves were found to have significant predictive probabilities in Conversation 1 (see red markers), though none of them had stronger practial effects compared to other moves from the Declaration (black markers), Proposal (blue marker), Administrative (orange markers), and Eliciting (green marker) categories of conversational contribution types.

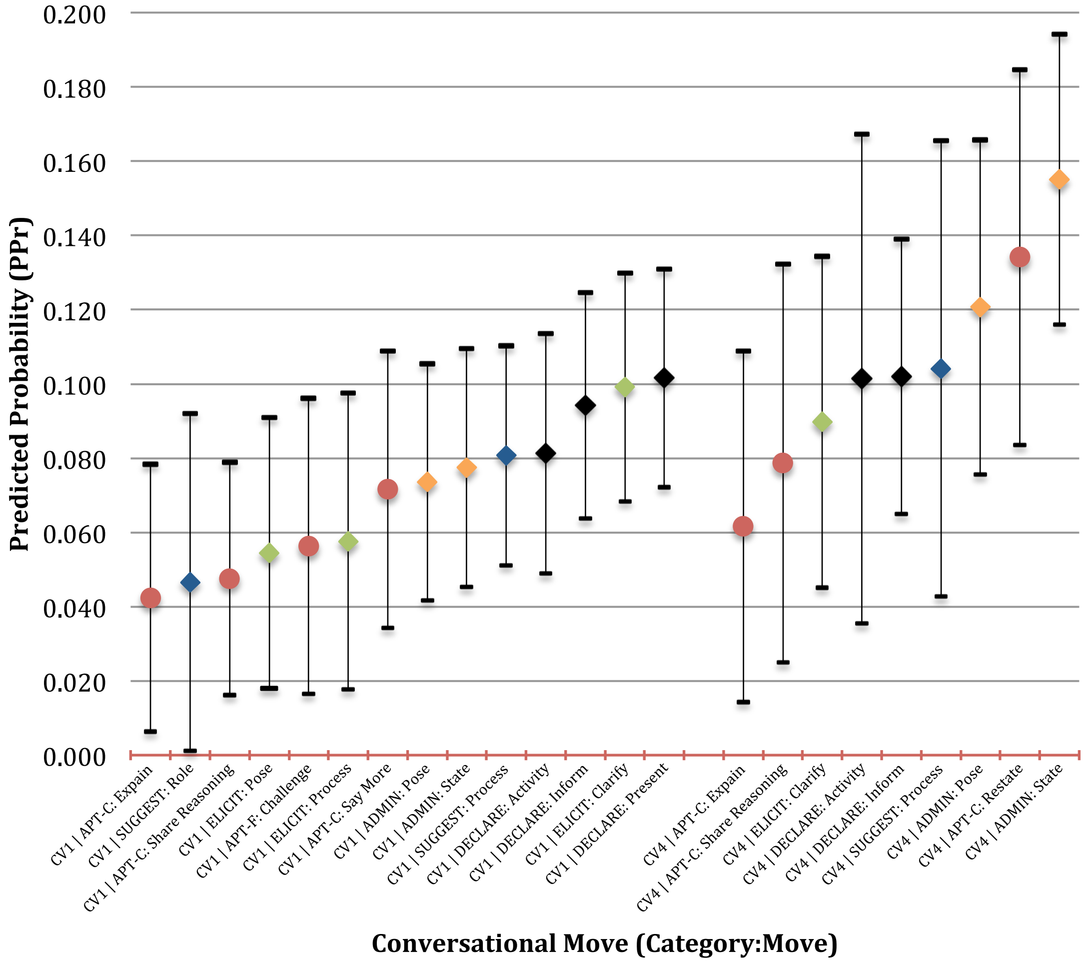

Figure 4.11. AME results associated with evidence of *Knowledge of Data*.

This suggests that overall, it was more probable that students' contributions that reflect conversational moves from these types of contributions would include evidence of data knowledge, more so than would APT moves. However, it is important to note that in Conversation 4, one APT move was among the moves with the strongest practical effects predictive of this outcome. Specifically, the APT-C move, *Restate* (i.e., at utterance that provided a summary of what someone else said, something the group decided, etc.), had an average marginal effect of 0.134 on the probability that evidence of *Knowledge of Data* would be presented. This finding suggests that this conversational move, compared to other types of moves, may be an imporant type of syntactic contribution regarding whether or not students include knowledge of data in their design thinking and discourse, in Conversation 4.

Skill of Data. This outcome was evident in student contributions that referenced how to use and/or apply data (i.e. references to numerical values, results tables, graphs, or research papers) in their design thinking. Only two APT moves were found to be significantly associated with evidence of the *Skill of Data* in design meetings contributions. Both of these moves were found in Conversation 1 and had relatively low marginal effects relative to other types of conversational moves. Specifically, the predicted probability (PPr) of skill of data being present in a student's contribution was 0.034 for utterances that were coded as the APT-Facilitative move *Challenge*, and 0.046 for those coded as the APT-Conversational move *Say More*. This finding suggests that, overall, it is more probable that students' use of conversational moves that were characterized as Declarations (i.e., *Activity, Present, Inform*), Proposals (i.e., *Process, Response, Approach*), and Administrative (i.e., *State, Pose*) in nature would yield evidence of this outcome in design meeting discourse, compared to APT moves.

Epistemology of Data. Similar to findings related to the knowledge of data, significant associations were found for APT moves in Conversations 1 and 4 (see Figure 4.12, below). Specifically, of 16 conversational moves significantly associated with this outcome in Conversation 1, almost half (7) were APT moves (indicated by red markers).

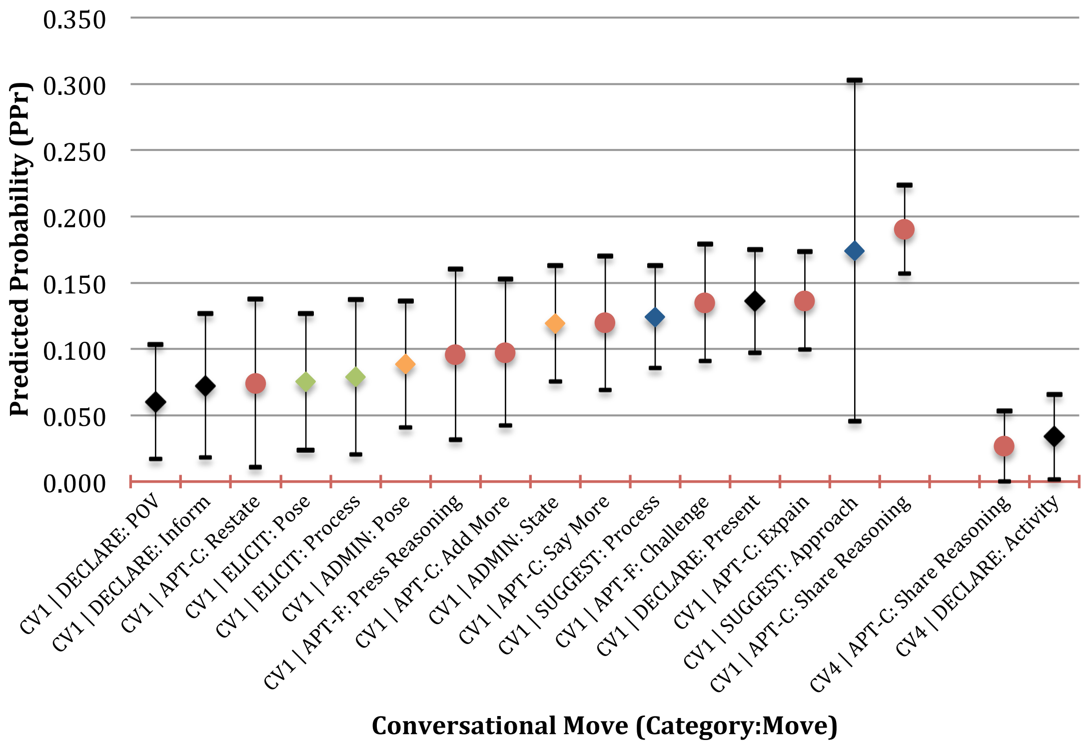

*Figure 4.12***.** AME results associated with evidence of *Epistemology of Data*.

Of these, the probability that evidence of *Epistemology of Data* would be present in a student's contribution increased by 0.190 if the utterance was characterized as APT-C: *Share Reasoning*, the strongest marginal effect of all moves associated with this outcome in this conversation. As previously noted however, this association is not particularly surprising given the nature of the *Share Reasoning* move (i.e., the rationale/justification of why one thinks something). Lastly, in Conversation 4, this same move was one of only two moves, second in predicted probability to the Declaration move, *Activity* (i.e., an utterance that conveys information to the group about the actions one, or someone else, has taken relevant to the completion of the task).

This finding suggests two things. First, the use of this APT move is particularly salient with regard to whether a student's contribution justified a design decision with the use of data, in the last design meeting (i.e., Conversation 4) prior the submission of student's final devices. Second, while the evidence indicates that both of these moves are significantly associated with evidence of the *Epistemology of Data* in student discourse in this conversation, the probability of such evidence being present is associated with two characteristically different types of contributions. More specifically, the use of the APT-C: *Share Reasoning* move characterizes a type of contribution that provides a substantive contribution to interactive discourse about how data should be used in students' design thinking as they make decisions about their device design. In contrast, the DECLARE: *Activity* move reflects a different type of contribution to discourse, namely one that supports the group's *process* because it is informing others about the activities of the group related to the completion of their task.

Identity

Having presented findings about the practical effects of APT related to data analysis (above), I now turn to a presentation of the practical effects of these moves with regard to epistemic evidence in student discourse about students' *Identity as Interns* and *as Engineers*. As previously reported, such evidence in design meeting discourse was found in moderate amounts in anywhere from 1% to 4% of student contributions. Results of logistic regression suggested that APT moves had little predictive power with regard to evidence in the epistemic domain of Identity. The interpretation of AME results indicated that only one APT-C move, *Share Reasoning*, had a practical, though limited, effect in relation to these outcomes, and is briefly descibed in what follows.

First, findings indicated that conversational moves found to be significantly associated with evidence of *Engineering Identity* (i.e., utterances in which students self-identified as an engineer, member of a team, working for company, etc.) had very low predicted probabilities overall (PPr range: 0.020 – 0.082). In this model, the average marginal effect of the APT-C: *Share Reasoning* on the probability of evidence of this outcome was 0.038, in Conversation 3. This suggests that Declaration moves (*Activity, Present*), Proposal moves (*Process, Approach, Response*), and Administrative moves (*Pose, State, Action*) are all better predictors of this outcome in student discourse. However, analysis of AME results indicated that with regard to Intern Identity (i.e., utterances in which students self-identified as an intern, staff member, or claimed ownership of professional items), the *only* move found to be significantly associated with such evidence was the APT-Conversational move *Share Reasoning* in Conversation 4. In this singular instance, the probability that evidence of this outcome would be present in a student's contribution had little practical effect (PPr=0.008), though still more than any other conversational move. This suggests that it is more probable that students will express their identity as an intern in discourse in the context of providing reasoning or clarification about why s/he thinks or believes something, than students would via other types of syntactic contributions.

Skills of Collaboration and Professionalism

Finally, the remaining two types of epistemic outcomes that occurred with a moderate frequency in student contributions are those for the *Skills of Collaboration* and *of Professionalism*. As indicated previously, these outcomes were evident in from ~1% to 6% of utterances in design meeting discourse. As above, results of logistic regression suggested that APT moves had little predictive power with regard to evidence in these outcome. The interpretation of AME results indicated that APT moves, with one exception, had limited, practical effect in relation to these outcomes, as will be described below.

Skill of Collaboration. As found above for outcomes related to Identity, the effects of conversational moves predictive of collaborative skill is student discourse (i.e., indications in contributions that students are engaging in collaboration or participation in a team meeting) are small and the only significantly associated APT move was APT-C: *Share Reasoning*. Specifically, in Conversation 2, the predicted probability of an utterance providing evidence of this outcome was 0.022 greater for utterances that shared students' reasoning than for most other conversational moves, with the exception of the Administrative moves *Pose* and *Action*. This suggests that it was more probable that evidence of students' collaborative skills would be evident in student contributions that asked teammates about what they were supposed to be doing (i.e., what was required of them) or informed group members about what s/he, will, should, or had done with regard to the "technical" business of the activity/task. In Conversation 3, however, APT-C: *Share Reasoning* was the *strongest* predictor of all conversational moves associated with this outcome. Specifically, the average marginal effect of this move on the probability that the associated utterance would also include evidence of the skill of collaboration was 0.083 (see Figure 4.13, below).

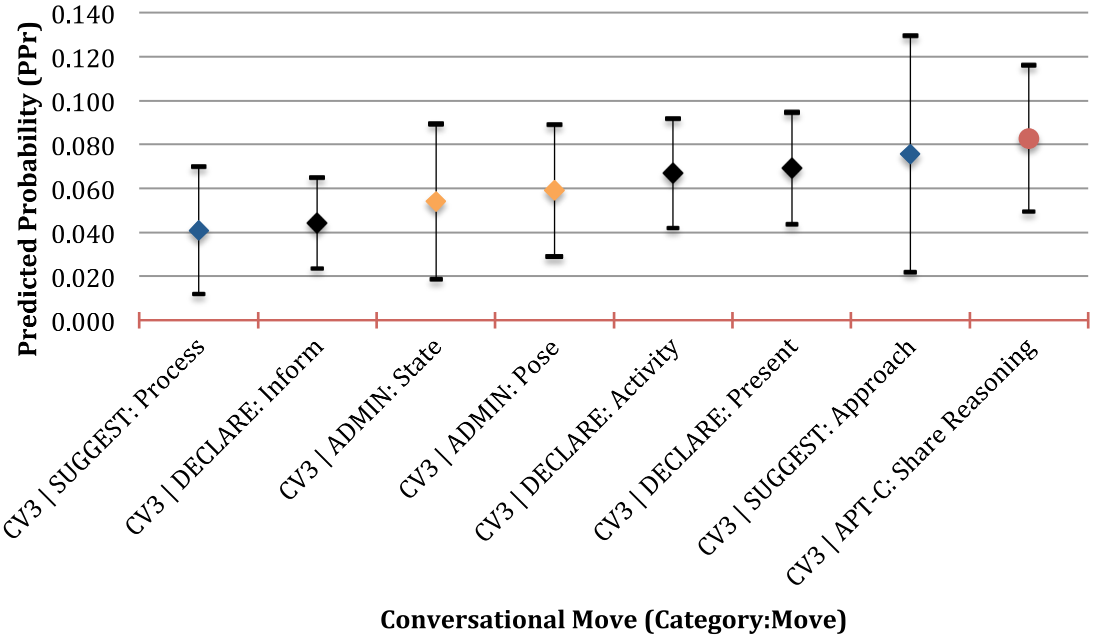

*Figure 4.13***.** AME results associated with evidence of *Skill of Collaboration* in Conversation 3.

Skill of Professionalism. Finally, analysis of AME results indicated that only two APT moves had a significant association with this outcome (i.e., utterances that convey that a student is using the company website, email, staff pages, etc. related to the internship). Specifically, in Conversation 1, the APT-Facilitative move *Press for Reasoning* had an average marginal effective of 0.072 on the probability that the associated utterance would also include evidence of the *Skill of Professionalism*. In Conversation 3, the predicted probability (PPr) of evidence of the *Skill of Professionalism* being present in a student contribution that was also coded as the APT-Conversational moves of *Share Reasoning* or *Add More* were 0.042 and 0.059, respectively. However, overall, moves associated with non-APT categories of talk (i.e., Administrative, Declarative, Proposals, Eliciting) yielded stronger predicted probabilities, than did APT moves, that evidence of this outcome would be present in student contributions in design meeting discourse.

4.6.3 Effects of APT moves related to epistemic outcomes with high evidentiary occurrence in student contributions

In the preceding section, I presented findings about the AME of APT moves in relation to epistemic outcomes that occurred *moderately* in *Nephrotex* design meeting discourse. In this final section, I present an analysis of AME findings with regard to epistemic outcomes that occurred at relatively *high* levels in student discourse. As presented above, such evidence is related to student contributions that included aspects of (1) Engineering Design (*Epistemology, Knowledge*, and *Skill*) and (2) device-specific technical Knowledge.

Engineering Design

Evidence in discourse that included reference to the *Epistemology, Knowledge* and *Skill* of engineering design was found in 5% to 31% of student contributions during design team meetings. The most prominent of these were related to evidence of design *Knowledge*, followed evidence of *Skill* and *Epistemology*. Analysis of logistic regression results indicated that some APT moves predicted epistemic outcomes in discourse related to such outcomes, though varied by conversation. As will be described below, AME results suggest that three APT-Facilitative moves – *Restate, Revoice,* and *Challenge* - have important, practical effects with regard to whether such evidence was found in student contributions.

Knowledge of Design. This outcome reflects evidence in students' contributions that referred to aspects of the device, prototype, experiment, or filtration membrane. In

Design Cycle 1, findings indicated that in Conversation 1, there were 19 conversational moves, representing all types of contributions (APT, Declarations, Eliciting, Administrative, and Proposals), significantly associated with evidence of engineering design *Knowledge* (see Figure 4.14, below). Of these, 9 (47%) were APT moves which, overall, were stronger predictors than other types of moves. In particular, the average marginal effects of using an APT-C: *Share Reasoning* (PPr=0.354) or an APT-F: *Challenge* (PPr=0.309) move on the probability that evidence of this outcome would be present in student contributions were among the strongest. This suggests that even if they are not unique, APT moves seem to be important types of contributions that yield evidence of design knowledge, in this conversation. In Conversation 1, teams discussed findings from their reviews of the literature and worked to rank and justify the importance of attributes they would use in the individual creation of devices for testing. It therefore makes that APT moves would play a more prominent role as students engaged in collaborative discourse to establish their rankings by, for instance, sharing their reasons, challenging one another's ideas, clarifying and explaining their points, and summarizing the work and thinking of the group.

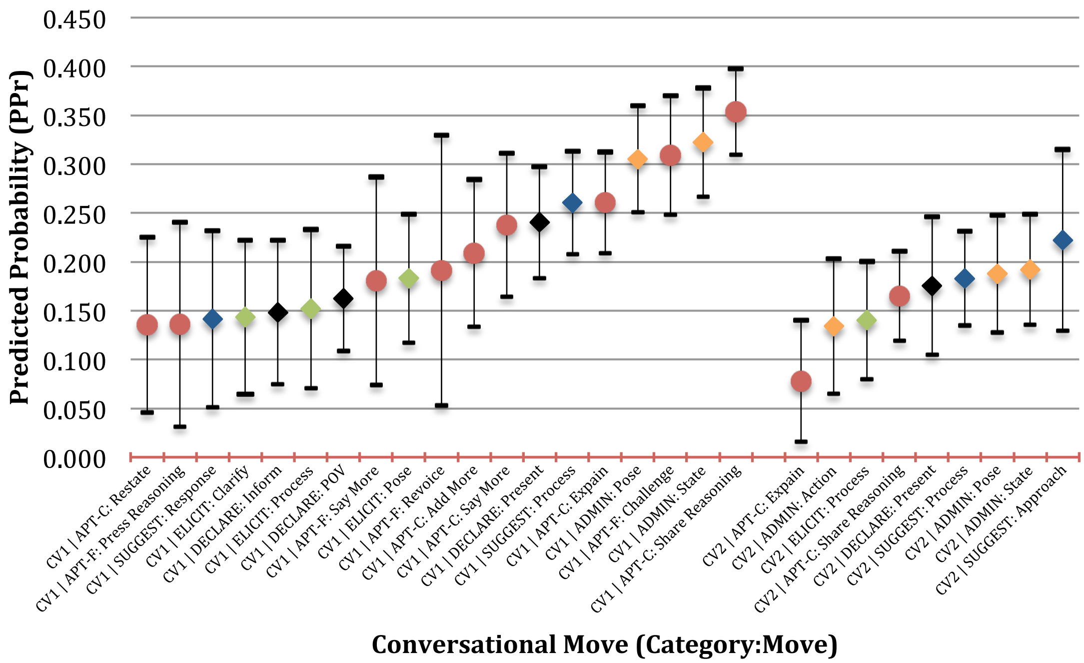

*Figure 4.14***.** AME results associated with evidence of *Knowledge of Design* in Conversations 1 & 2.

Conversation 2 had fewer significant predictors (9) of this outcome, only two of which were APT moves (APT-C: *Share Reasoning* and APT-C: *Explain*), and each had weaker predicted probabilities than most other conversational moves. In this conversation, the focus of the meeting was to determine which five (of twenty-five possible) devices the *team* would submit for testing. Although I would have expected APT moves to play a more prominent role in this conversation, results suggest that it was more probable that evidence of students' design knowledge would be evident in Administrative contributions (i.e., those that asked (*Pose*) or informed (*State*) teammates about what they were supposed to be doing) and in students' Proposals about how the group should proceed with their task (*Process*) or a skills-based strategy related to completing their task (*Approach*).

The next set of findings pertains to the AME of conversational moves related to engineering design *Knowledge* in Design Cycle 2. In Conversation 3, the only APT move found to be predictive of this outcome (of twelve moves) was APT-C: *Share Reasoning* (see Figure 4.15, below), among the weakest of the predictors in the regression model for this conversation. This suggests that compared to other types of syntactic contributions, APT moves had little practical association with evidence of student's design knowledge in this conversation.

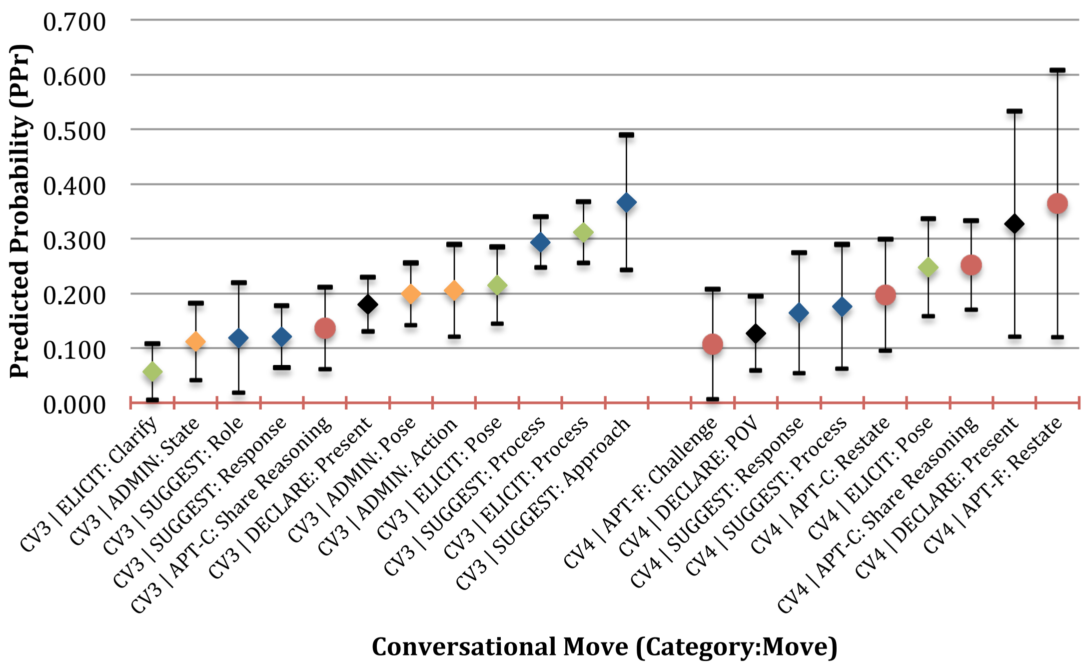

Figure 4.15. AME results associated with evidence of *Knowledge of Design* in Conversations 3 & 4.

In Conversation 4, however, APT moves accounted for 44% (4/9) of moves found to be significantly associated with the *Knowledge of Design* being evident in a student's conversational contribution (found in 31% of contributions). Of particular interest is that the strongest predicted probability of this outcome being present was 0.364 for utterances that were characterized as APT-F: *Restate* (i.e., prompting a teammate to repeat something s/he, or the group, said or decided on). This finding makes conceptual sense because in this conversation (teams' final design meeting) students were tasked with coming to consensus about which *single* device to submit as their "final" device. As such, efforts by students in groups to ensure clarity about decisions seem particularly salient. Additionally, this finding suggests that it was more probable that students' use of this conversational move, relative to others, would be seeking confirmation about what was said or decided *with regard to* aspects of engineering design knowledge. Lastly, it is interesting to note that APT-C: *Share Reasoning* was a significant predictor of evidence of design knowledge being included in students' contributions in all of the design meetings, though varied in effect size by conversation.

Skill of Design[27]. The average marginal effects of conversational moves significantly associated with this outcome (i.e., utterances that reflect the action of design development, prioritizing, tradeoffs, and making design decisions) in Conversations 1 and 2 are displayed in Figure 4.16, below. In Conversation 1, 50% (n=7) of the conversational moves predictive that student contributions included evidence for engineering design *skill* were APT moves. Of these, the average marginal effects of APT-C: *Explain*, APT-F: *Challenge*, and APT-C: *Share Reasoning* on this outcome were among the predictors with the strongest effects (PPr=0.147, 0.157, and 0.186, respectively). This finding suggests APT moves in discourse are an important type of syntactic contribution with regard to this particular outcome.

[27] Negative AME results are not displayed, none of which were APT moves.

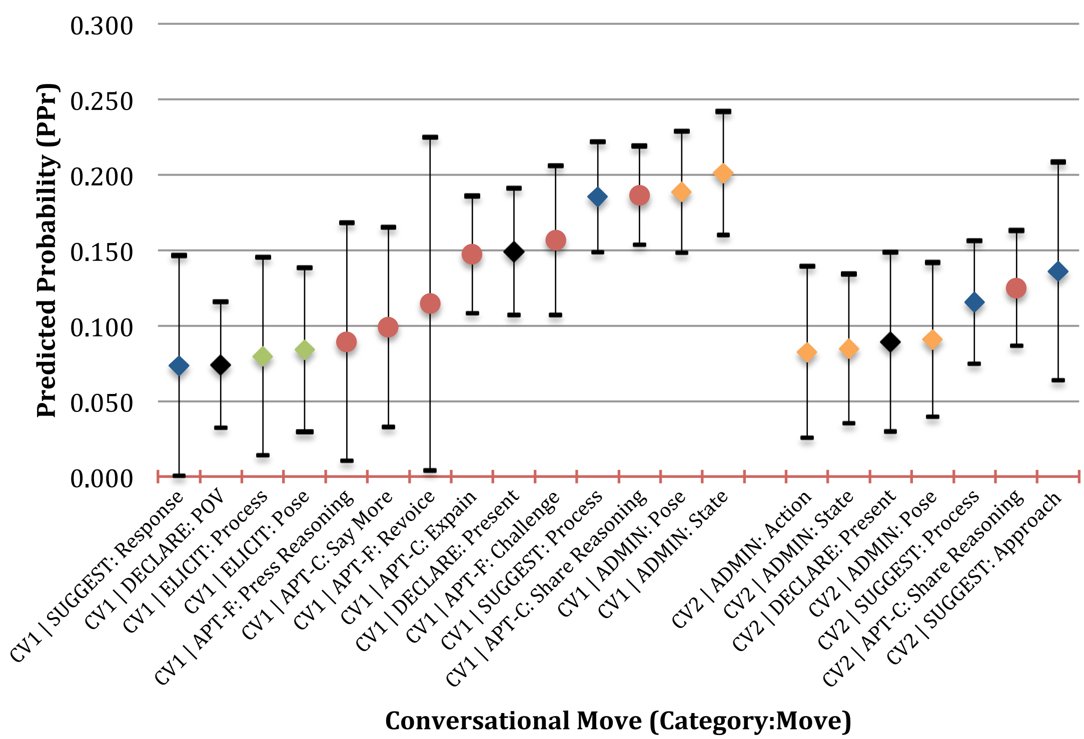

*Figure 4.16***.** AME results associated with evidence of *Skill of Design* in Conversations 1 & 2.

Of the moves that were significant predictors of this outcome in Conversation 2, APT-C: *Share Reasoning* had one of the strongest practical effects - the predicted probability (PPr) that evidence of the design *Skill* would be present was 0.125 for contributions that were coded for this move, second in effect size to the use of the SUGGEST: *Approach* move (PPr=0.136).

Fewer APT moves were found for conversations in Design Cycle 2. As displayed in Figure 4.17, below, only one APT move (APT-C: *Share Reasoning*) in Conversation 3 had a significant effect on the probability of evidence of design skill being present in students' contributions (PPr=0.104), and was lower than most other moves in the logistic model. However, three APT moves were found to have significant effects in

Conversation 4, the strongest of which was the APT-F move, *Revoice* (PPr=0.177), which is an utterance that reframed what someone else said, expressed, proposed, etc. in order to check/clarify understanding. Similar to the use of APT-F: *Restate* in Conversation 4 for design *Knowledge* (above), this suggests the saliency of students seeking clarity about their group's thinking with regard to how they are incorporating the skill of data use in their design thinking as they prepare their final device for submission.

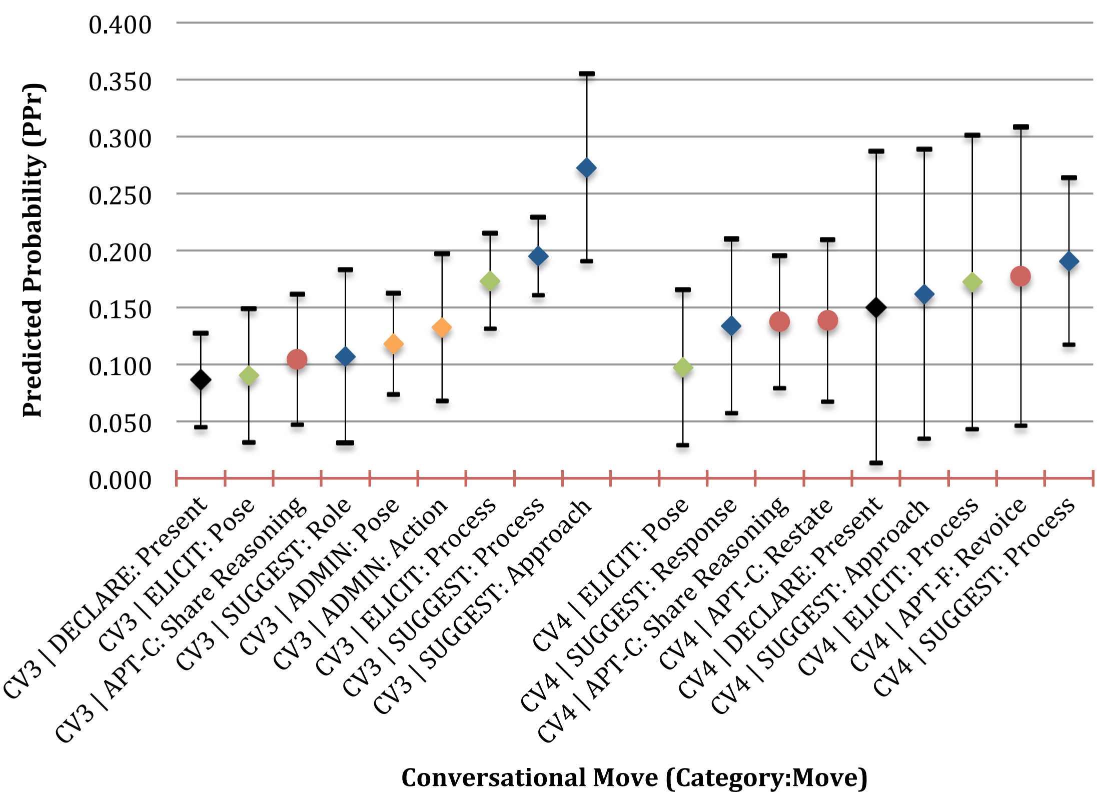

*Figure 4.17***.** AME results associated with evidence of *Skill of Design* in Conversations 3 & 4.

Epistemology of Design[28]. Of the three epistemic domains related to engineering design, *Epistemology* (i.e., evidence in an utterance that indicated a justification of design decisions using design terms/references) had the fewest number of conversational moves

[28] Negative AME results not displayed, none of which were APT moves.

predictive of evidence in student utterances in discourse, and none were found in Conversation 1 (see Figure 4.18, below). As before, it is not surprising that the APT-C move, *Share Reasoning,* was associated with this outcome. The average marginal effect of this move on the probability of evidence of engineering design *Epistemology* was 0.121 in Conversation 2, 0.094 in Conversation 3, and 0.180 in Conversation 4. Lastly, in Conversation 4, the highest predicted probability (of all associated moves) of design epistemology being present in contributions was 0.205 for utterances that were coded as APT-F: *Restate*. This finding parallels what was found for this move, in this conversation, related to design *Knowledge*.

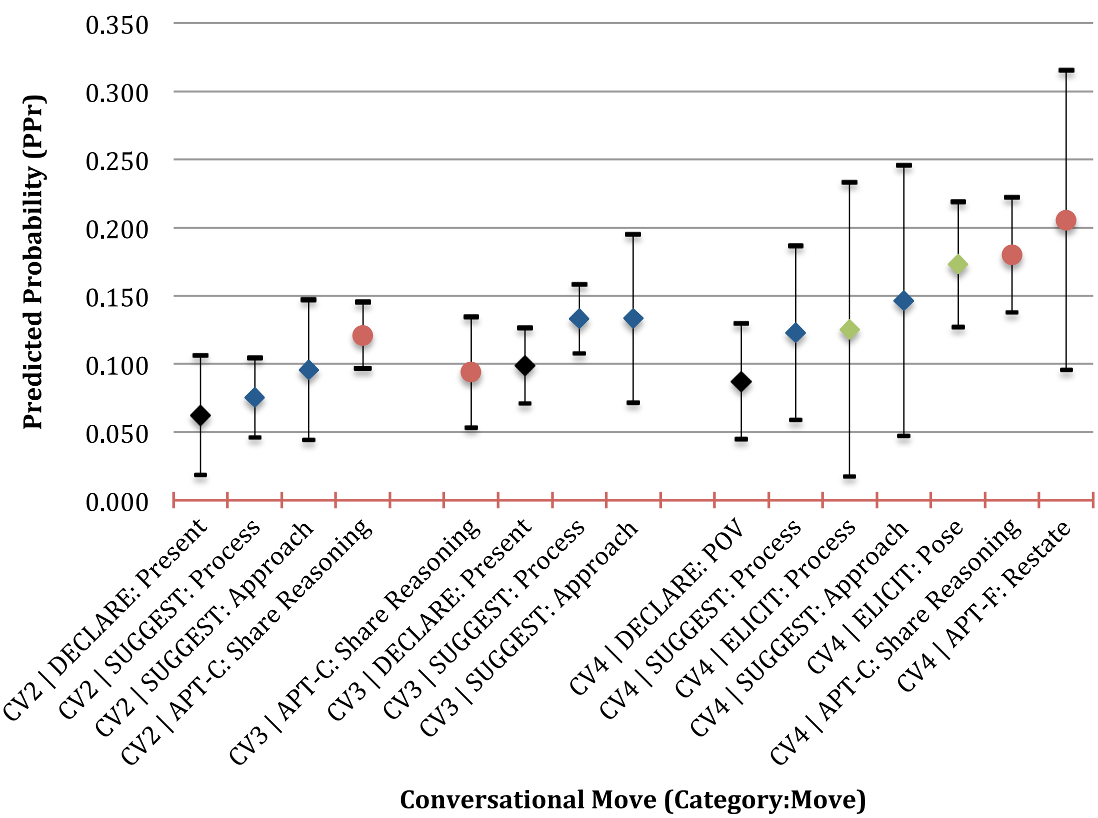

Figure 4.18. AME results associated with evidence of *Epistemology of Design*.

Device-specific Technical Knowledge

Lastly, the remaining type of epistemic outcomes that occurred with a high frequency in student contributions are those related to device-specific *Technical Knowledge* (i.e., Attributes, CNT, Surfactant, Materials, Manufacturing). As presented earlier in this chapter, such outcomes were evident in as few as 2%, and as high as 40%, of utterances in design meeting discourse. Analysis of logistic regression results indicated that: (1) anywhere from 2, to as many as 17, conversational moves were significant predictors in these models, depending on the outcome and the conversation; and (2) the number of APT moves in these models varied by conversation. Of additional interest, is that of all of the epistemic outcomes in this study, conversational moves found to be significantly associated with technical knowledge outcomes had, on average, the highest predicted probabilities in my analysis. In what follows, I present findings from my analysis of the average marginal effects of conversational moves associated with these epistemic outcomes.

Brief summaries of findings about the AME of APT moves in relation to epistemic outcomes related to technical knowledge and presented below[29]. As will be shown, evidence indicates that the APT-Facilitative move, *Revoice*, and the APT-Conversational move, *Restate,* had some of the strongest practical effects in many conversations with regard to whether evidence of technical knowledge was found in student contributions. This finding suggests that these two moves, both of which

[29] In contrast to the figures presented in previous sections that included all conversational moves found to be significant predictors in regression models, the figures presented for this set of epistemic outcomes only include the AME of APT moves. This is due to the number of conversational moves found in each model, which makes the figures difficult to read. As previously indicated, a summary table to all AME findings can be found in Appendix H.

characterize utterances that reframe or summarize someone else said, expressed, proposed, etc. in order to check/clarify understanding, are important types of syntactic contributions in discourse that yield evidence of these outcomes. This finding also makes practical sense because the use of such moves would help students to keep track of the vast amounts of information they need to understand the implications and details of their design decisions.

Knowledge of Surfactant. Of the conversational moves found to be significant predictors for evidence of surfactant knowledge in student contributions, APT moves accounted for 50% (4/8) in Conversation 1, 56% (9/16) in Conversation 2, 45% (5/11) in Conversation 3, and 33% (1/3) in Conversation 4. Findings indicated a repeated presence, with strong predicted probabilities, of the APT-C: *Restate* and APT-F: *Revoice* moves related to this outcome in design meeting discourse (Figure 4.19, below).

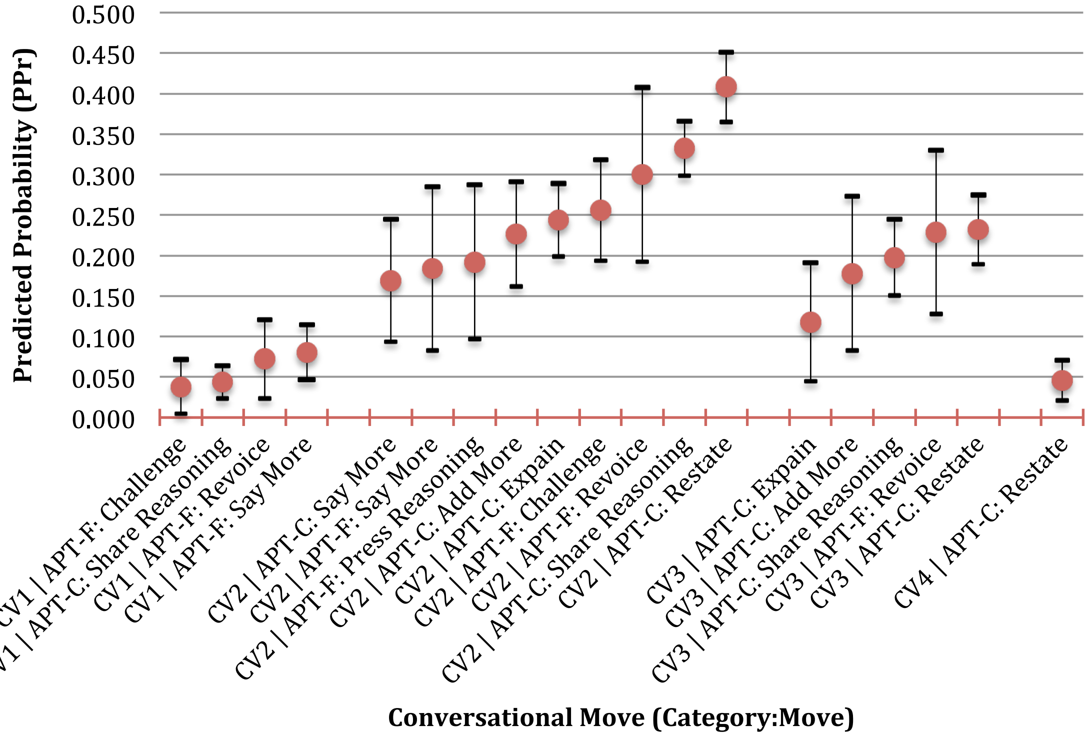

*Figure 4.19***.** AME results associated with evidence of *Knowledge of Surfactant* (only APT moves displayed).

Knowledge of CNT. Findings indicated that APT moves were significant predictors of evidence of CNT knowledge in student contributions in Conversations 1, 2 and 4 (Figure 4.20, below)[30]. More specifically, APT moves accounted for 55% (6/11) and 56% (9/16) of all predictive moves in Conversations 1 and 2, respectively, and 1 of only 4 moves (25%) in Conversation 4. In Conversation 2 in particular, the average marginal effects of APT-C: *Share Reasoning*, APT-F: *Revoice*, and APT-C: *Restate* on the probability that the associated utterances would also include evidence of CNT knowledge evidence were 0.229, 0.226, and 0.207, respectively (see Figure 4.20, below).

[30] No moves, of any type, were significant in Conversation 3.

The only move with a stronger effect size in this conversation was DECLARE: *Present* (0.238) (not displayed).

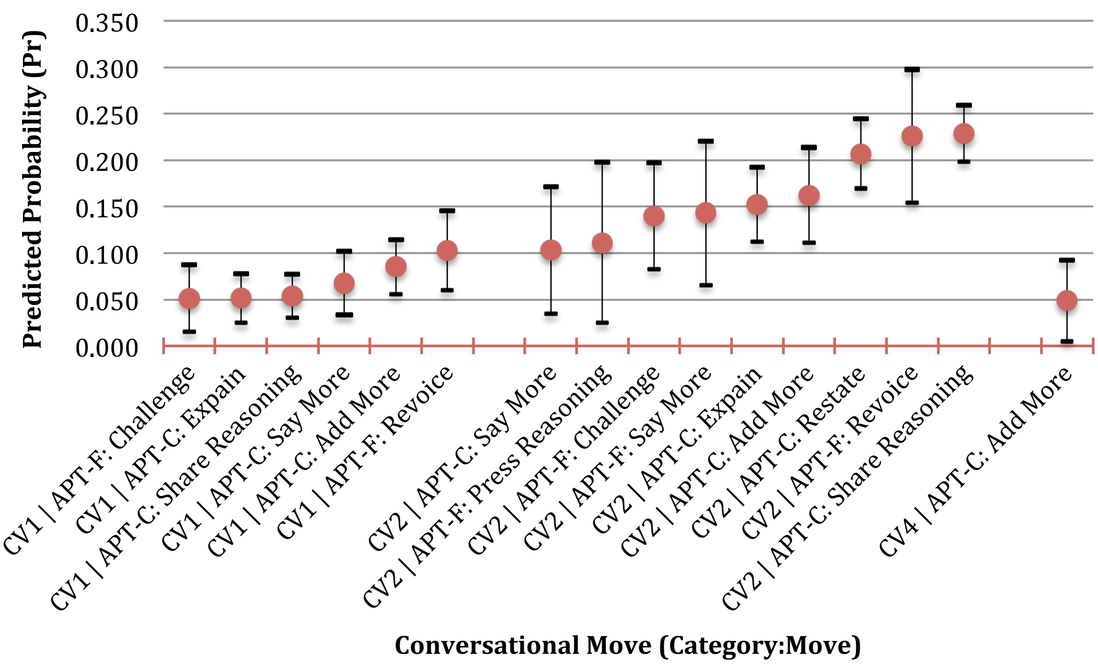

*Figure 4.20***.** AME results associated with evidence of *Knowledge of CNT* (only APT moves displayed).

Knowledge of Materials. In Conversation 1, no APT moves were found to be significantly associated with evidence of *Knowledge of Materials* in student utterances. However, APT moves accounted for 40% (4/10) of conversational moves predictive of this outcome in Conversation 2. In particular, the predicted probabilities of evidence of this outcome being present in student contributions were 0.105 for APT-C: *Restate* and 0.098 for APT-F: *Revoice*, and were the strongest of the 10 predictive moves in this conversation. Of additional interest is that the APT-C: *Restate* move was significantly associated with this outcome in Conversations 2, 3, and 4 (see Figure 4.21, below).

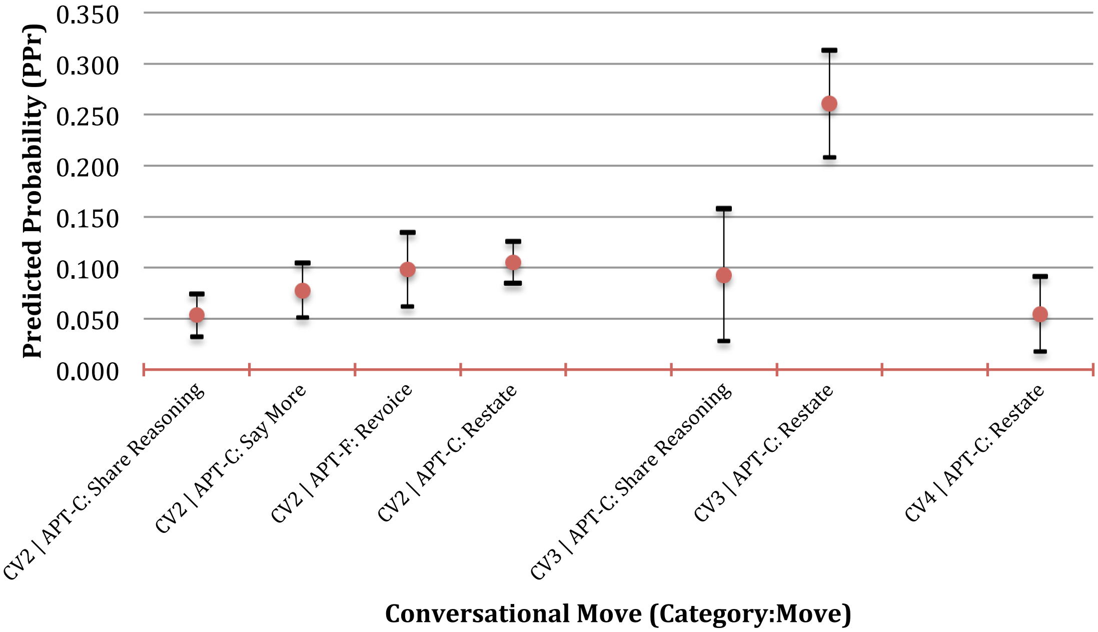

Figure 4.21. AME results associated with evidence of *Knowledge of Materials* (only APT moves displayed).

Knowledge of Manufacturing. Findings related to the association between APT moves and evidence of manufacturing knowledge are similar to those found for knowledge of materials. Among APT moves, APT-C: *Restate* was among those with the strongest practical effects in Conversations 2, 3, and 4 (Figure 4.22, below).

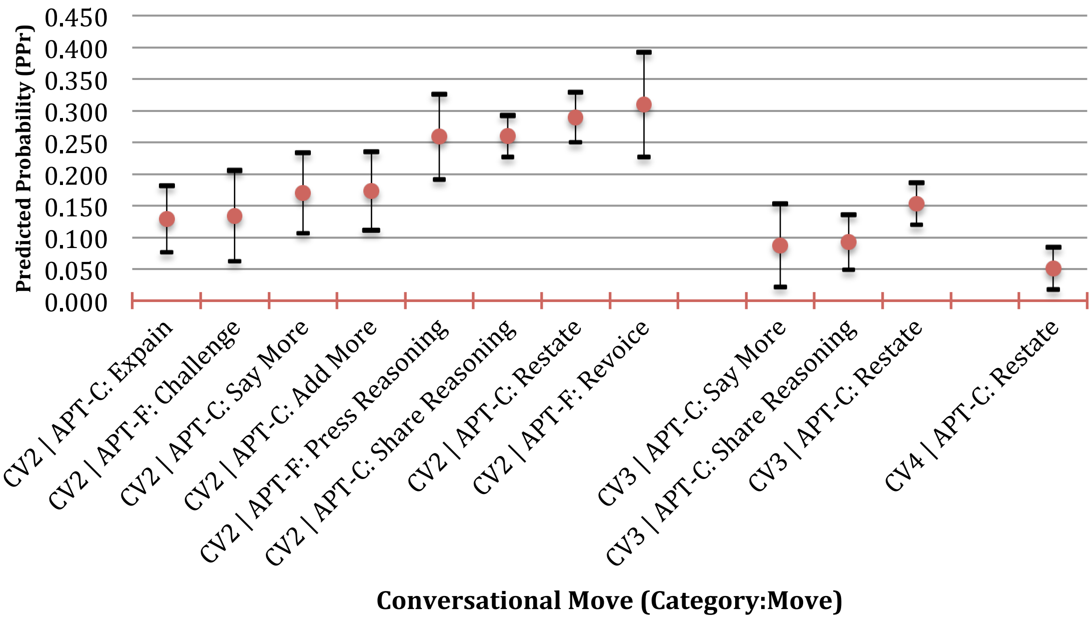

*Figure 4.22***.** AME results associated with evidence of *Knowledge of Manufacturing* (only APT moves displayed).

Conversation 2 had the most conversational moves predictive of this outcome and 50% (8/16) of them were APT moves. Additionally, APT-F: *Revoice* and APT-C: *Restate* had the strongest predicted probabilities (PPr) of all moves in this conversation, with average marginal effects of 0.309 and 0.290, respectively, on the probability that evidence of manufacturing knowledge would be present in a student's contribution. APT moves accounted for 38% (3/8) of all conversational moves significantly associated with this outcome in Conversation 3, and 1 of 4 (25%) in Conversation 4. No conversational moves of any type were found to be significant predictors of this outcome in Conversation 1.

Knowledge of Attributes. Overall, AME findings related to evidence of attribute knowledge in student contributions were the strongest in the sample. Of the conversational moves found to be significant predictors of this outcome, APT moves accounted for 53% (9/17) in Conversation 1. In this conversation, the average marginal effect of APT-C: *Restate* on the probability of evidence of this outcome was 0.694, the strongest practical effect of all 17 predictors in this conversation. Fifty-seven percent (4/7) of moves significantly associated with this outcome in Conversation 2 were APT moves, three of which had higher predicted probabilities than all other moves: APT-F: *Challenge* (PPr=0.20), APT-C: *Add More* (PPr=0.210), and APT-C: *Share Reasoning* (PPr=0.254).

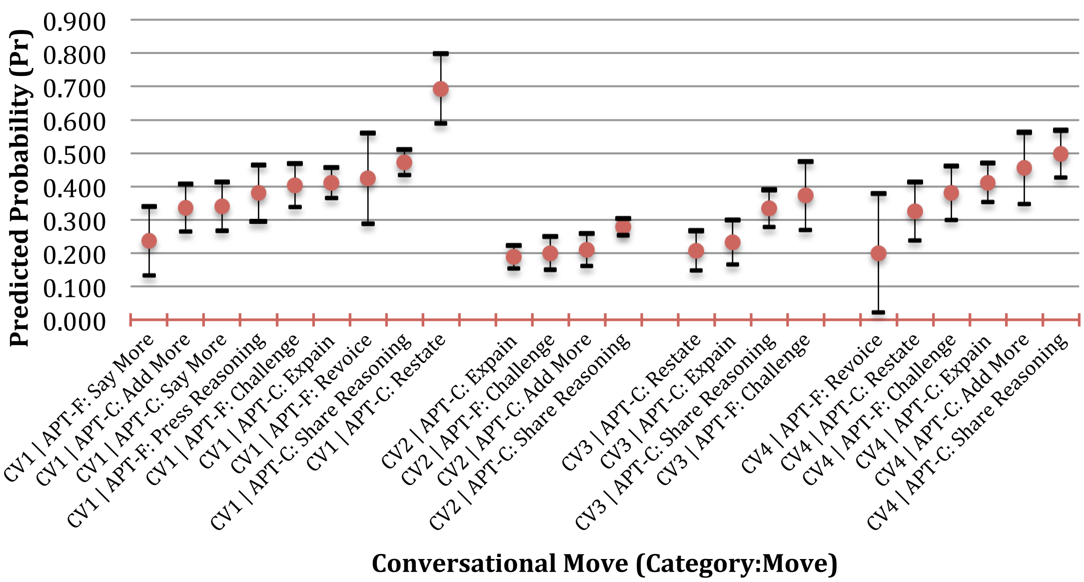

*Figure 4.23***.** AME results associated with evidence of *Knowledge of Attributes* (only APT moves displayed).

APT moves accounted for 44% (4/9) of moves in Conversation 3, and two of them - APT-F: *Challenge* (PPr=0.372) and APT-C: *Share Reasoning* (PPr=0.335) - had the highest average marginal effects, after DECLARE: *Present* (PPr=0.464). Lastly, 56% (6/11) of moves in Conversation 4 were APT moves. With the exception of DECLARE: *Present* (PPr=0.440), they had stronger predicted probabilities than any other conversational moves, ranging from 0.325 (APT-C: *Restate) to* 0.497 (APT-C: *Share Reasoning*).

4.7 Summary of RQ1 Findings

In the previous sections of this chapter, I presented the results of my analysis which found that 11 of 14 (79%) APT moves (6 Facilitative; 5 Conversational) were associated with evidence of a variety of epistemic elements in at least one, and in many instances, multiple conversations, across the domains of *Knowledge, Epistemology, Skills, Identity*, and *Values* in student contributions in design team meeting discourse. The average marginal effects (i.e., practical effects) of these associations varied by move and conversation. In some instances they had stronger, and in other instances weaker, practical effects in relation to other moves found to predict evidence of different epistemic outcomes in student utterances. A synthesis of these findings reveals that 50% (7/14) APT moves can be described as having "unique" associations with epistemic outcomes (see Table 4.3, below), as determined by: (1) the strength of association relative to other conversational moves, if any, in logistic regression models; or (2) its recurrent association, in relation to other types of contributions, with a particular outcome in logistic regression models.

Table 4.3

Summary of unique associative trends (cell values indicate which conversation(s))

Epistemic Element/ *Domain*	**APT-Facilitative (APT-F)**			**APT-Conversational (APT-C)**			
	Re-voice	*Restate*	*Challenge*	*Share Reasoning*	*Restate*	*Add More*	*Explain*
Design							
Epistemology		4					
Knowledge	1	4	1 | 4				
Skill	1 | 4	4	1				
Client							
Epistemology			H1 | H2	H1 | H2		H1	H1 | H2
Knowledge			1 | 3	1 | 2 | 3		1 | 3	1 | 3
Values			H1	H1		H1	H1
Consultant							
Epistemology				1 | 2 | 3 | 4			
Values				3 | 4			
Technical Knowledge	1 - 4				1 - 4		

These associative trends can be summarized as follows. First, in general, different "types" of epistemic outcomes were associated with the use of APT moves in student discourse, and varied depending on whether the moves were "conversational" or "facilitative" in nature. In particular, the outcomes most uniquely associated with *Conversational* APT moves were those related to design constraints that students needed to consider in their task, namely those related to considerations of "the client" and "the consultant" (highlighted in green). These were also found to be the least common epistemic elements evident in student contributions in design team meeting discourse. The outcomes most uniquely associated with *Facilitative* APT moves were those related to aspects of engineering design, which were found to be among the most common epistemic elements evident in student contributions (highlighted in blue). These differences in the associations between the type of outcome and the type of APT moves suggest that they served different "functional" roles in discourse related to yielding evidence of different types of outcomes. Second, there were trends in *when* these moves matter that varied by conversation and/or design cycle. This suggests that the APT moves more uniquely associated with evidence of different epistemic outcomes in student contributions also served different functions at different stages of the design process.

My analysis found little evidence to support a claim that APT moves had a unique association, if any, with epistemic evidence that occurred in moderate amounts in student discourse, namely outcomes associated with Data Analysis (*Epistemology, Knowledge, Skill*), Identity (*as Intern, as Engineer*), the *Skill of Collaboration*, or the *Skill of Professionalism*. In other words, conversational contributions that were characterized as Declaration, Eliciting, Proposal, and Administrative moves were all better predictors, overall, of these types of epistemic outcomes. This does not suggest that collaborative conversation moves (i.e., APT moves) were *ineffective* at yielding such evidence, but that other types of moves were more prominently and/or consistently effective at doing so.

4.8 Discussion

In this section I present a discussion of my findings for research question one. A broad, synthetic summary discussion of findings, and threats to validity, will be presented in the final chapter of this dissertation.

This part of my study used chat-log (i.e., utterance) data from four, 30-40 minute long design team meeting conversations held by 110 unique student groups to empirically test my hypothesis for research question one. I hypothesized that there would be unique patterns of epistemic frame elements associated with different *Academically Productive*

Talk (APT) conversational moves in design team meeting discourse in the *Nephrotex* virtual internship. To test this hypothesis, I regressed each of the 20 possible epistemic outcome variables (i.e., semantic evidence of epistemic elements) that could be present in a contribution on the predictor variables drawn from the coding of discourse that characterized the syntactic contributions (i.e., conversational moves) found in design meeting discourse. I then calculated and presented the average marginal effects (i.e., practical effects) of all moves (predictors) found to be significantly associated with each of the epistemic elements (outcomes). I expected to find evidence that collaborative conversational moves (i.e., APT moves) would be found in my analysis of student discourse because *Nephrotex* is an "intentional" CSCL environment designed, in part, to mediate, support and facilitate group interaction wherein students learn and build knowledge collaboratively (Stahl, 2006) in order to design a medical device that met a series of pre-determined constraints.

My analysis found that APT moves characterized 41% (n=6109) of all student design team meeting utterances (N=15068). Broadly speaking, the fact that such a high proportion of student contributions in *Nephrotex* reflected characteristics of APT in an environment where students were not explicitly required to use them (i.e., non-scripted) reflects how the use of APT in discourse effectively supports reasoned participation and fosters effective discourse (Michaels et al., 2008; Adamson et al. 2013; Resnick et al. 1993, 2013). Furthermore, the prominent and endogenous use of APT moves affirms that the design of the simulation is well-structured in terms of requiring collaborative communication and active learning, at least in part, to be successful (Blumenfeld et al., 1996; Rahman et al., 2010; Mercer, 1996; Soller et al., 1998). In other words, students' frequent use of APT-style contributions in discourse points to the fact that the simulation was specifically designed to foster and engender collaborative interaction through discourse.

Such a high use of APT in design team meetings can also be interpreted in light of the types of cognitive and social skills detailed in the literature that are integral to collaborative problem solving (c.f., Griffin at al., 2012; O'Neill et al., 2003; OECD, 2013). For instance, my analysis suggests that the use of APT was an indication that students were demonstrating an ability to enact important skills such as participation and cooperation (i.e., contributing knowledge to the group), task regulation (i.e., understanding the information and resources needed to complete the task), knowledge building (i.e., contributing information and skill-based knowledge), social regulation (i.e., negotiating misunderstandings and conflicts of ideas), and perspective taking (i.e., considering the ideas put forth by others).

More specifically, the strong or recurrent associations found in my analysis for specific types of APT contributions points to how students were engaged in discourse that reflected their ability to integrate information (i.e., *Revoice, Restate*), use judgment (i.e., *Share Reasoning, Explain, Challenge*), identify alternatives (i.e., *Challenge*), and evaluate consequences (i.e., *Add More, Explain*). Furthermore, the use of facilitative APT moves, in particular, reflect how students in *Nephrotex* were also able to exercise leadership (i.e., coordinating activities and of the team), employ interpersonal skills (i.e., improving quality of interaction), and communicate effectively (i.e., clarifying other's ideas) in the service of work on their design problem. Future design- or intervention-based research could examine these relationships in more detail to determine whether

APT could be used to formatively assess a student's ability to demonstrate such criteria and/or as a measure of group collaborative process and interaction in a simulation-based environment, such as *Nephrotex*.

Another valuable contribution of this study is empirical evidence that there was a relationship between some aspects of *how* students talk (i.e., the syntactic function of contributions) and *what* they talk about (i.e., the semantic nature of those contributions) with regard to APT. More specifically, my analysis finds that certain APT moves were more likely than other types of conversational moves to yield evidence associated with particular epistemic elements in student contributions. These findings are consistent with prior research that has established that different types of conversational contributions (i.e., speech acts) play different functional roles in discourse (Wilson and Hartung, 2015), as well as with findings reported by Hartung and Wilson (in press) that unique patterns of association between conversational moves and specified outcomes can be identified.

In what follows, I discuss these findings that point to how some APT moves are uniquely associated with evidence of different epistemic outcomes in conversational contributions, and that some of these associations vary by the phase of the design process and by the type of APT move (i.e., *Facilitative* or *Conversational*). That is, particular APT moves appear to "matter," and at different phases of the design process, with regard to yielding different types of epistemic evidence in student discourse.

Which, and when, APT moves matter

Two broad patterns were found in my analysis. First, three *Facilitative* APT moves (which were used in relatively low frequencies) were found to be recurrently associated with epistemic outcomes related to engineering design (which were present in relatively high frequencies) at the onset and at the culmination of students' collaborative work. One explanation for this pattern of association is that these types of moves played a functional/practical role in group discourse when the prompting and/or challenging of other students served to ensure that the group was clear about their understanding and application of engineering design principles. Future design-based research could test whether such associations would be more prominent overall, or occur in more design meetings, if students were prompted to use such facilitative moves in their discourse.

Secondly, and conversely, three *Conversational* APT moves (which were used in relatively high frequencies) were found to be prominently associated with epistemic outcomes related to the consultant and the client (which were present in relatively low frequencies), primarily when new groups met for the first time. The fact that these moves were more effective than any other types of moves at including these outcomes, at these design phases, makes conceptual sense because students were working to understand what they have individually researched (in the case of Conversation 1) and what their prior groups have experimented with in their designs (in the case of Conversation 3). As such, the nature of these moves appears to have served the functional role of introducing ideas that "belonged" to the individual into group discourse. In what follows, I discuss the unique associations of these conversational moves with their respective epistemic outcomes in greater detail.

Inclusion of the "the client"

The results of my analysis show that, in student discourse in *Nephrotex,* the use of three APT-Conversational moves (*Share Reasoning, Add More, Explain*) and one APT-

Facilitative move (*Challenge*) were consistently and positively associated with students' demonstration of a key outcome criteria outlined by ABET (2011). Specifically, students should demonstrate an ability to engage in a design process that considers design constraints in relation to the health and safety of the end user of the product (i.e., *the Client*). Said another way, the inclusion of "the client" in the course of a group's design meeting discourse in *Nephrotex* was enhanced when students made conversational contributions that provided a justification or rationale for a claim, built upon the ideas of others, explained why an idea under consideration was right or wrong, and/or challenged an idea or conclusion put forth by a teammate.

The strongest predicted probabilities of these APT moves on client-related evidence in student contributions were found for evidence of client *knowledge* in Conversation 1 (PPr range: 0.22 - 0.39). In comparison, the predicted probabilities of these same APT moves were rather low for client-related evidence in the domains of *Epistemology, Values*, and after Conversation 1, *Knowledge* (PPR range: 0.01 - 0.06). One explanation for the discrepancy in the magnitude of these practical effects is that, in Conversation 1, evidence of *Client Knowledge* as a proportion of all utterances (6.7%) was roughly four times that of *Client Values* (1.6%) and over twice that of *Client Epistemology* (3.1%). Simply put, students talked about their knowledge of the client's health and safety in this conversation more than they did about the value of that knowledge, or about how that knowledge should be used to justify their design decisions. As a result, stronger effects were detected in the logistic model for this outcome, in this conversation.

However, even with such low practical effects with regard to these outcomes overall, the fact that APT moves were the only, or most prominent, types of conversational moves associated with evidence of the client in student contributions points to the value of their use as strategic syntactic contributions in the course of collaborative conversations as students worked to complete their task in the simulation. That is, these APT moves are more effective types of conversational contributions, when compared with other types (i.e., Declarations, Eliciting, Proposals, Administrative), for yielding evidence of epistemic evidence related to the client.

My analysis also shows that *when* these moves matter in student discourse varies by the type of client-related outcome (i.e., *Values, Knowledge, Epistemology*). First, the association between the APT moves discussed above and evidence of *Values of Client* in student contributions was only consistently found in the first design cycle (Conversations 1 & 2). This suggests that the use of these APT moves was more salient in the initial phases of the internship experience, and less so in the latter, with regard to yielding evidence that students valued the health and well-being of the client. One explanation for this is that this trend reflects the early efforts of groups to make meaning of the variety of constraints they were individually tasked with considering prior to their group's convening. Another explanation is that, once groups discussed these values with regard to their initial thoughts about device prototypes, it is possible that they were carried over to their design cycle two groups already embedded in the prototypes their new groups were tasked to consider. Relatedly, as the focus of group discourse shifted to more contributions related to engineering design and data analysis, both of which steadily increased in frequency of occurrence over the course of the internship, evidence of client values diminished as well.

Second, with regard to evidence of client knowledge in student contributions, APT moves appeared to matter most in Conversations 1 & 3. This is an interesting pattern that suggests that the use of these APT moves were particularly important at the onset of students' work in each of their two groups. This finding makes sense because in the initial conversations of each design cycle of the simulation, students needed to share and synthesize the work they had done *prior* to meeting for the first time. In Conversation 1, this is reflected in how groups spent time working through and organizing the research and thinking done individually by students prior to their first design meeting. Similarly, in Conversation 3, groups had to spend time organizing the unique research, data and thinking conducted in each student's prior group. What this means is that these types of collaborative, conversational contributions supported groups as they engaged in the work of sorting out what they know and/or need to know with regard to the client in relation to making decisions about their initial prototypes to submit for testing in each of the two phases of the internship (i.e., Design Cycle 1 & Design Cycle 2).

Lastly, that fact that consistent associations between APT moves and evidence of client epistemology were found overall in both design cycles indicates that these moves were effective at facilitating the inclusion of the client in the justification of design decisions from the onset to the culmination of their collaborative group work.

Inclusion of "the consultant"

The results of my analysis show that the use of the APT-Conversational move, *Share Reasoning*, in student discourse in *Nephrotex* design meetings was consistently and positively associated with evidence that students were accounting for the needs and constraints imposed on their design process, another student outcome outlined in ABET (2011) criteria. In the *Nephrotex* simulation, this is represented by the constraints put forth by the internal project consultants that students were expected to consider in the design of their device. Said another way, the inclusion of "the consultant" in a group's design meeting discourse in *Nephrotex* was facilitated when students made conversational contributions that provided reasoning or justification for why one thinks, believes, says, or claims something.

Evidence of consultant-based outcomes in student contributions related to epistemology and values was relatively low (< 2%) as a proportion of all types of epistemic evidence found in design meeting discourse contributions. Given the relative infrequency of such evidence, the low predicted probabilities (i.e., all <0.05) found for this APT move make sense given the limited amount of observations in the regression models. However, in the absence of a greater variety of conversational moves or stronger practical effects, the fact that these moves were consistently associated with these outcomes means that they served an important functional role in student discourse.

The *Share Reasoning* move was found to have a practical, albeit small, effect (PPr range: 0.01 - 0.04) with regard to predicting that evidence of epistemology of the consultant would be evident in student contributions in all of the conversations. On the one hand, it makes conceptual sense that this move would be significantly associated with semantic evidence of the *justification* of design decisions with regard to the consultant's needs (i.e., Epistemology). On the other hand, the fact that this move was *not* found to be more *uniquely* associated with the epistemology of design or data, for instance, suggests that although other types of conversational contributions may yield such evidence with regard to these outcomes, the use of this move is particularly salient for the inclusion of *the Consultant* in design meeting discourse.

Interestingly, the probability of evidence of valuing the constraints imposed by the consultants being present in a student's contribution when this move was used in discourse was most prominent in the second design cycle (i.e., Conversations 3 & 4). It is important to note that my analysis showed that it is not that other types of moves were better predictors of such evidence being present in a student's contributions in the first design cycle, but that no moves were found to be associated at all. This means that using the *Share Reasoning* move in Design Cycle 2 appears to matter as it relates to incorporating evidence of valuing the consultant's interests. Said another way, students' use of the *Share Reasoning* move in discourse not only was used to justify their design decisions (i.e., *Epistemology*) in a way that reflected their *valuing* the consultant's interests, but also that the value of these interests were also used more generally when presenting a rationale for a claim.

Inclusion of "engineering design"

Evidence of design-related epistemic outcomes in student contributions were among the highest as a proportion of all types of epistemic evidence found in design meeting discourse. Design knowledge, in particular, steadily increased from 17% in Conversation 1 to 31% in Conversation 4. As presented above, a variety of conversational moves were associated with these outcomes, and in many instances were found to have stronger practical effects on design-related outcomes. However, the results of my analysis indicate that three APT-Facilitative moves (*Revoice, Restate, Challenge*) were commonly found to be among those moves associated with students' inclusion of evidence of epistemic elements related to engineering design in the domains of epistemology, knowledge, and skill. These elements codify two criteria outlined by ABET (2011) as central STEM learning outcomes, namely, student's ability to "... apply knowledge of mathematics, science, and engineering," and to "use the techniques, skills, and modern engineering tools necessary for engineering practice." Said another way, indications of student's knowledge and application of engineering design principles in the course of design meeting discourse in *Nephrotex* was, in part, enhanced when students made facilitative contributions that *prompted other students* to repeat or clarify what someone else has said or that the group decided, and/or that challenged an idea or conclusion put forth by a teammate.

Given the relative overall infrequency of the *Revoice* (0.5%), *Restate* (0.4%), and *Challenge* (2%) moves in student discourse in relation to other types of moves, this is a particularly interesting finding. As will be discussed in what follows, the fact that these moves were commonly associated with these outcomes suggests that they served an important functional role in student discourse at specific phases of the simulation experience. In particular, my analysis shows that the associations between the aforementioned facilitative moves and design-related outcomes are most prominent in the first and/or last design meetings (i.e., Conversations 1 & 4). This indicates that the use of these APT moves, along with other types of moves, supported students discourse about engineering design in the: (1) initial phase of their work, when as a team, they were tasked with designing a set of device prototypes for testing; and the (2) final phase of their design process when teams worked to refine their final device for submission.

For instance, the practical effects of the facilitative move, *Revoice*, ranged from

0.16 to 0.19. This means that when students reframed what someone else said to clarify their understanding, and in particular at the onset of their collaborative work as a team, doing so supported student efforts to make meaning of what the group understood about the knowledge and application of engineering design principles. This finding is important given how infrequent this move was in student discourse in Conversations 1 and 4 (0.6% and 0.8%, respectively), as a proportion of all types of contributions. This means that even though this move was rarely used by students, when it was, it had important effects related to yielding evidence of engineering Design *Knowledge* and *Skill* in these conversations.

Analysis also showed that the facilitative move, *Restate*, had practical effects in Conversation 4 ranging from 0.14 – 0.36, and was associated with all three design-related epistemic outcomes (*Epistemology, Knowledge, Skill*). The fact that this move was found to be associated with outcomes in all three of these epistemic domains in the last team meeting shows that prompting a teammate to repeat something that someone else, or the group decided on, was an effective strategy for ensuring that the group's thinking about their final design decision was aligned. As before, this finding is particularly salient given how infrequent this move was in student discourse in this conversation (0.6%), as a proportion of all types of contributions. Said another way, even though the facilitative move, *Restate*, was rarely used, when it was it had an important effect related to yielding evidence of what students know about engineering design (*Knowledge*), how they should apply that knowledge in practice (*Skill*), and how they were using that knowledge to justify their decisions (*Epistemology*), in their final design meeting.

The last facilitative move found in my analysis to be commonly associated with evidence of design-related outcomes (*Knowledge* and *Skill*) in student contributions was *Challenge*. The practical effects of a student expressing a different conclusion or understanding of other's ideas and thinking about their knowledge and/or application of engineering design ranged from 0.11 to 0.31. This move was found to be associated with such outcomes in the first and last design meetings of the simulation. This suggests that there is a relationship between the stage of the design process and the functional role this facilitative move played in student discourse.

In particular, using the *Challenge* move in the first design meeting points to how students indicated to others that the research they conducted (individually), prior to meeting as a team for the first time, led them to draw different conclusions about what knowledge and skills were most important to consider in their first pass at designing device prototypes. At this early stage in groups' work, these clarifications are important and support the development of a group-level understanding from which to make subsequent decisions. Similarly, students' use of this move in the final design meeting indicates that it played an important role to ensure that students' knowledge of engineering design was accurately reflected in the final device they submitted for testing and evaluation. Although this move was more commonly used in discourse than *Revoice* and *Restate* in Conversations 1 and 4, it was still relatively infrequent overall (3%), as a proportion of all types of contributions. This means that even though this move was not used often, when it was it played an important role in yielding evidence that students were incorporating their knowledge of engineering design and how to apply it (i.e., *Skill*) in their design team meetings.

Inclusion of "technical knowledge"

My analysis found that almost all APT moves were associated with at least one outcome related to *Technical Knowledge* (i.e., Attributes, Manufacturing, CNT, Surfactant, Materials) in at least one conversation, and in many instances, were found to be associated with multiple outcomes in multiple conversations. That being said, syntactic contributions of all types were found to be associated with these outcomes across all of the design team meetings in *Nephrotex*. This means that, overall, APT moves were not more or less effective than other types of conversational moves as a means of introducing or including evidence of *Technical Knowledge* into their design meeting discourse.

However, my analysis did reveal a pattern concerning the consistent association of two APT moves with evidence of technical knowledge in student contributions, namely the Facilitative move, *Revoice*, and the Conversational move, *Restate*. The predicted probabilities that these APT moves would yield evidence related to technical knowledge ranged from 0.08 - 0.40 for *Revoice*, and from 0.05 - 0.70 for *Restate*. Although the size of their practical effects varied widely, the variation was consistent in relation to conversation and outcome.

This is an interesting finding because, although both of these moves describe a student contribution that directly accounts for what someone else in the group has said, expressed, proposed, etc., the *intention* of each move is different. For instance, the Conversational move, *Restate*, characterizes an unprompted contribution in discourse that summarizes what someone else has said. In contrast, the Facilitative move, *Revoice*, is a contribution that reframes what someone else has said in an effort to clarity, or check for, understanding. Therefore, this move is facilitative in the sense that it is a prompt for someone else in the group to respond. The fact that these characteristically different moves were both found to be consistently associated with evidence of technical knowledge in student contributions throughout the simulation suggests that efforts by students to "take stock" of what the group is talking about was one strategic way for students to ensure clarity about their device specifications as they worked to keep track of the vast amounts of information, details, and fine-grain specifications they needed to account for in the design of their devices. In other words, regardless of whether a student was seeking clarity about, or merely summarizing, what the group had discussed, the use of these moves supported the inclusions of technical knowledge in discourse in all design team meetings.

Summary

As discussed above, my analysis is generally consistent with the literature reporting how different types of conversational contributions serve different functional roles in discourse and that unique patterns of association between conversational moves and specified outcomes can be identified (Wilson and Hartung, 2015; Hartung and Wilson, in press). My findings also expand upon this literature.

Specifically, whereas Hartung and Wilson (in press) report fairly discrete associations between particular conversational moves and different types of outcomes in their study, my analysis found that the associations between particular APT moves and evidence of epistemic outcomes in student conversations were associated with a *variety* of epistemic *domains*. In particular, the uniqueness of the associative patterns found in my study were, overall, between the type of APT move (i.e., Facilitative or

Conversational) and the type of epistemic *element* (i.e., engineering design, consultant, client, technical knowledge). This implies that the use of collaborative conversational moves, as codified by APT, is not related to evidence of discrete outcomes (e.g., conceptual learning/higher cognitive complexity), but rather such moves are effective at yielding evidence across a range of outcome types and levels of cognitive complexity.

As such, this study extends findings by Hartung and Wilson (in press) with regard to context and setting. Specifically, their study was based on self-reported learnings from informal learning conversations where there were no specified outcomes that participants were tasked with producing, nor was there a problem to be "solved." In contrast, this study considered a less biased measure (i.e., evidence of epistemic elements in student utterance data) to examine associations between conversational moves and outcomes in a simulated environment where participants were engaged in a specified task to solve a design problem. Said another way, in the context of an environment that provides a situated learning experience, conversational contributions were associated to more nuanced types of evidence, a finding that sheds light on the relationship between how people talk and what they talk about in such an environment.

It is also important to note that the findings reported and discussed above should be interpreted with a degree of caution because my analytical strategy for this research question adopted an exploratory mode of research. In particular, it set out to investigate a number of possible relationships, rather than a small set of more specific hypotheses, using a dataset that integrated semantic and syntactic features of discourse. This is an approach that, to my knowledge, has not yet been utilized in studies of student discourse in simulations. Because of this, my analysis includes a large number of non-independent statistical tests that may have resulted in Type I errors, returning false positives on the relationships identified. Therefore, the findings reported here, and what they suggest, provide a starting point for future investigations that should: (1) test more specific hypothesis about the relationships between a targeted subset of APT moves, and when and how they may matter for supporting more robust and integrated epistemic discourse; and/or (2) incorporate methods for multiple testing correction in their design to account for multiple comparisons. Further implications for practice and future research are addressed in the following section.

4.9 Implications

As previously noted, the use of APT in practice and research is most commonly done in a scripted context (i.e., students and/or facilitators are tasked with using the APT framework in a CSCL environment). Therefore, these findings contribute to and expand the extant literature on the use of APT in CSCL environments by considering its effects in a simulation-based game environment, and suggest a number of implications for practice and avenues for future research to pursue.

One implication for practice implied by my findings is that students could learn how to strategically use APT in their discourse as a way to improve the overall collaborative nature of their discourse. This learning could occur prior to, or be embedded in, the simulation experience. A few examples related specifically to my findings could look like the following. A student on each design team could be expected to take on the role of facilitator in key moments to ensure that groups are integrating important design elements in their collaborative conversations by, for instance, prompting others to *revoice* or *restate* what has already been discussed, and even to *challenge* the ideas of others more about the design process the team is engaged in or how they are employing that process in practice. Students could also be prompted and/or encouraged to *add to* and/or *explain* the ideas put forth by others to support the better integration, and ultimately increase the frequency of inclusion, of design constraints related to the client and consultant in their discourse. Additionally, students could be prompted to step back from their process from time to time, whether prompting others to do so or doing so oneself, to ensure that all the device specifications under consideration are well accounted for and clear to all members of the group.

A second implication has to do with mentor scripts, whether automated or in real-time, that could prompt students to use APT-style moves in discourse in the simulation. Simulation designers could consider the findings from this analysis as they further develop and refine the mentor scripts used in the game environment to include the explicit introduction of APT-style facilitation moves and/or ways of encouraging students to use such moves. Future research, using a controlled intervention study, could test whether the intentional use of APT scripts in the simulation would yield more and/or different evidence of epistemic outcomes in student discourse, which in turn, may result in a change in how a student's or a group's epistemic frame is modeled using Epistemic Network Analysis.

A third implication has to do with the coding of epistemic discourse. Although this study was not directly concerned with the associations of non-APT types of moves (i.e., Declarations, Eliciting, Proposals, Administrative), a review of my results from regression analysis and AME suggests that certain types of syntactic contributions are strongly associated with epistemic outcomes, in sometimes surprising ways. The nature of these contributions raises interesting questions about how a student's, or a group's, epistemic frame is modeled using ENA. Future research could be conducted where the epistemic coding scheme (i.e., semantic coding) is paired with conversational move coding (i.e., syntactic coding) to allow for the disaggregation of epistemic evidence in utterances by different types of syntactic contributions.

For example, my analysis found very high average marginal effects for Administrative moves (i.e., *Pose, State, Action*) in the first design cycle for evidence in utterance data related to engineering design. Such contributions could be construed as reflecting efforts by "the student" who is participating in the simulation to figure out their "task" (i.e., what they are supposed to do), rather than a substantive contribution by the "student-as-intern" immersed in the simulated engineering design process. Therefore, future research, using a paired coding approach, could test whether these, and similar, findings make a significant difference in the types of epistemic networks that groups and/or players develop over the course of the simulation (as would be tested using ENA). If so, the epistemic discourse coding scheme could be modified to account for different types of syntactic contributions if distinguishing between "the student" and the "student-as-intern," for example, were of interest to simulation designers with regard to representing the development of a student's or a group's epistemic frame.

Finally, additional research in the same vein could explore whether accounting for both the semantic *and* the syntactic aspects of discourse could lend support to in-game mentors (or automated mentors) for the real-time identification of differences in groups' discourse that would trigger the activation of particular mentor scripts, re-directions, and/or interventions that could support the improvement of student's collaborative interaction and, ultimately, outcomes.

Chapter 5

Research Question Two (RQ2)

Are there differences in the connections among different epistemic frame elements that groups make in their discourse with respect to Academically Productive Talk *(APT)? What, if any, group-level characteristics are associated with these differences?*

5.1 Chapter Overview

As described in Chapter 3, to answer RQ2 I conducted ENA to test for differences in the richness, density, and location of connections made to epistemic frame elements in groups' design meeting discourse in relation to their use of APT (drawn from the qualitative coding of discourse that characterized such types of syntactic contributions). As will be presented in what follows, findings from my analysis indicate that there were differences in the frequency and types of connections made during design meeting discourse among groups that used varying degrees of APT. No differences were found in the first design cycle (Conversation 1 & Conversation 2) of the internship. Such differences were only found in the second design cycle of the *Nephrotex* internship (Conversation 3 & Conversation 4), and the findings differed by conversation. Additionally, findings from these two conversations suggest that the group-level characteristics of experience level (i.e., novice or advanced), gender-balance, and contribution equality were associated with APT use in design meeting discourse, and varied by conversation as well.

In particular, the results of my analysis suggest that groups that used more APT in their discourse in Design Cycle 2 conversations, as a proportion of all types of conversational contributions, were better able to focus on a number of critical, domain-specific (i.e., epistemic) connections that needed to be made in their discussions as they collaborated on the completion of their task. More specifically, these critical connections resulted in a better integration of *the consultant* (i.e., his/her needs, interest, and expectations) and *data analysis* (i.e., knowledge, skill, and epistemology) into students' design thinking in Conversation 3, and a better integration of *the client* (i.e., the patient's wellbeing, health, comfort and/or safety) into students' design thinking in Conversation 4. The differences in the findings for Conversations 3 and 4 suggest that the relationship between the use of APT and the types of epistemic connections made in discourse are context specific, and related to the different foci in the conversations (i.e., organizing as a new group to identify viable models for testing in Conversation 3; converging on final device proposals in Conversation 4).

5.2 Organization of Chapter

The remainder of this chapter is organized as follows. First, in order to provide context for the reporting of my results, I provide an orientation to how ENA results were interpreted in the context of my study. Following this, because each conversation was examined separately in my analysis, I present the unique results for each *Nephrotex* design meeting conversation where significant differences were found regarding the effects of APT in separate sub-sections, beginning with those found in Conversation 3, and followed by those found in Conversation 4. In the context of each conversation, I first present a brief overview of the group's focal task (i.e., expected outcome) in their design meeting, along with a summary of the distribution of conversational moves (i.e., syntactic contributions) found in that meeting's conversation. Next, I present the results of ENA, which includes a summary of statistical tests and the display of epistemic network models that highlight the differences in the frequency and types of connections made comparing groups with differing levels of APT use in their discourse. Following this, I present qualitative evidence of the ENA results as they are reflected in representative samples of student discourse in the *Nephrotex* internship. These samples highlight the relationship between the syntactic use of APT by group members and the associated semantic evidence of epistemic elements, if any, in such contributions in group discourse. Next, I present ENA results pertaining to group-level characteristics associated with APT use. Each sub-section concludes with a brief summary of findings for that conversation. This chapter concludes with a discussion of findings from my analysis of data related to research question two, as well as implications for practice and future research.

5.3 Orientation to ENA results reporting

A plot of the focal equiload nodes for this analysis is presented in Figure 5.1 (below)[31]. In the analysis of design meeting discourse in *Nephrotex* that follows, groups that made more connections, relatively, with the skill of engineering design in their discourse loaded positively (> 0.2) on ENA dimensions 1 (Client/Design Skill) or 2 (Consultant & Data Analysis/Design Skill) (the x and y axis, respectively). Likewise

[31] ENA equiload nodes, such as those presented in Figure 5.1, are used to interpret ENA dimensions in a way that is analogous to the way a PCA loadings plot is used to interpret PCA dimensions. For ENA, the use of the equiload nodes has advantages over the loadings for interpreting ENA dimensions because the number of ENA loadings is large (i.e., ‘N choose 2,’ where N is the number of variables) compared to one loading/variable in PCA (Wesley Collier, *Research Assistant* with Epistemic Games Group, personal communication, September 18, 2015).

these groups made relatively fewer connections, on average, with other elements (e.g., knowledge of data; values of the consultant; knowledge of engineering design, etc.). Groups that loaded negatively (< -0.2) on ENA dimension 1 (negative on the x axis) made relatively more connections, on average, with the knowledge of engineering design and the "the client" (i.e., the values, knowledge, and epistemology of *the client*), and relatively fewer connections, on average, with engineering design skill and other epistemic elements. Finally, groups that loaded negatively (< -0.1) on ENA dimension 2 (negative on the y axis) made relatively more connections, on average, with engineering design *knowledge*, "data analysis" (i.e., the skill, knowledge, and epistemology of *data*), and "the consultant" (i.e., the values and epistemology of *the consultant*). ENA dimension 1 accounts for 29% of the variance in the data. The second dimension (ENA2, y-axis) accounts for 18% of the variance in the data (47% total variance). Each group's scores for epistemic discourse from each conversation, and in each design cycle, were multiplied by the loadings for ENA1 and ENA2 and used by the ENA tool to generate network models for analysis.

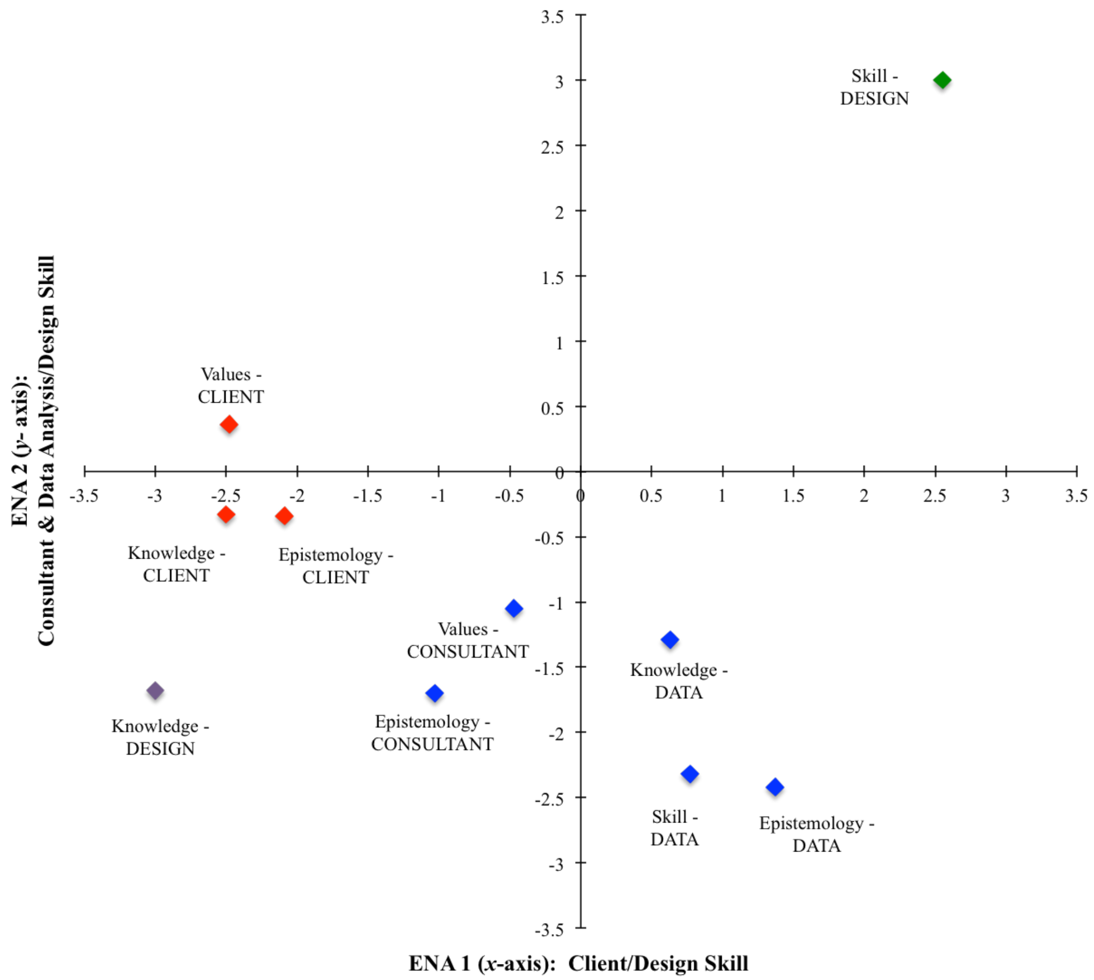

Figure 5.1. Plot of equiload nodes for ENA Dimension 1 and ENA Dimension 2.

5.4 Analysis of findings for Conversations 1 and 2

5.4.1 Context/Orientation

The conversations in Design Cycle 1 are those in which student interns met with members of their first design team groups in the *Nephrotex* virtual internship. In their first design team meeting (i.e., Conversation 1), interns shared and discussed the findings from their individual reviews of the literature. Following this, they worked together to rank and justify five device attributes that they would all use to create five prototype devices, individually. In Conversation 2, design teams re-convened to share these devices, and then as a team, determine the five best devices they would submit for performance testing. The median distribution of groups' (N=55) use of each conversational move type in Conversations 1 and 2 are presented below (Figures 5.2 and 5.3, respectively).

These graphs highlight that APT moves characterized almost 50% of all of conversational contributions (i.e., utterances) in Design Cycle 1 conversations (48% in Conversation 1; 44% in Conversation 2). Additionally, although representing a small proportion of APT moves, the median proportion of APT-Facilitative moves in Conversation 1 was almost twice that found in Conversation 2 (9% vs. 5%). Finally, while Declaration moves accounted for a similar proportion of utterances in Conversations 1 and 2 (21% and 17%, respectively), their median distribution in Conversation 1 (Figure 5.2) was twice that of Proposal (10%), Eliciting (10%), and Administrative (9%) moves.

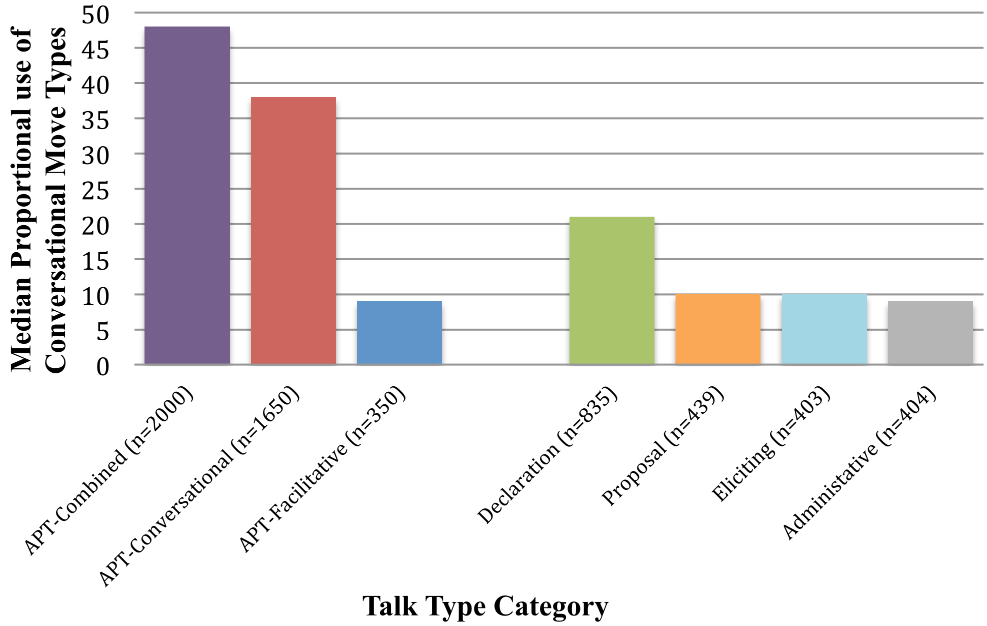

Figure 5.2. Median proportional distribution of conversational moves, by category, in design team meeting discourse in Conversation 1 (N=4048).

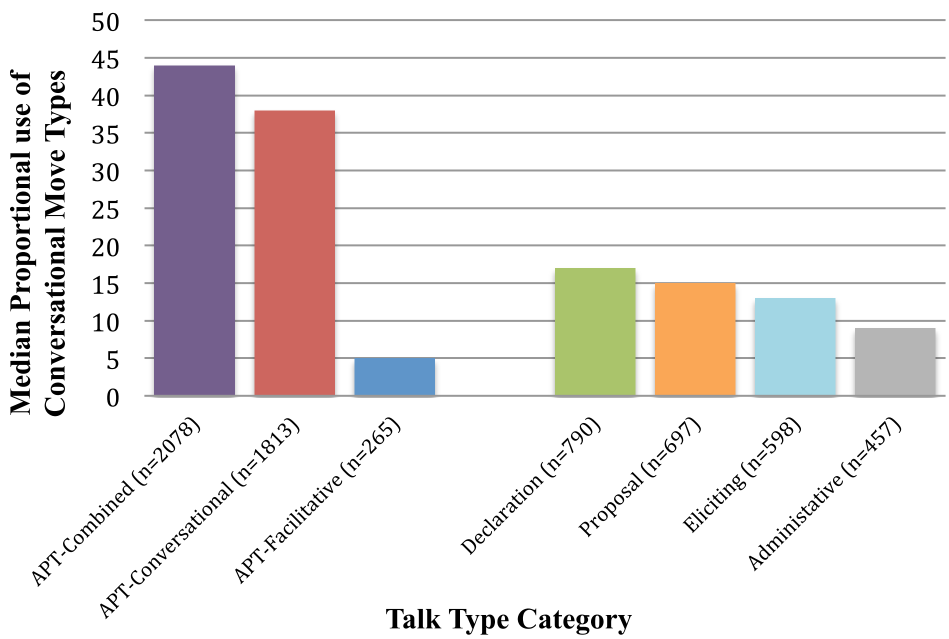

Figure 5.3. Median proportional distribution of conversational moves, by category, in design team meeting discourse in Conversation 2 (N=4620).

5.4.2 ENA Results for Design Cycle 1 Conversations (1 & 2)

ENA results did not indicate any significant differences in the frequency or types of connections made in Conversations 1 or 2 when comparing groups that used differing degrees of APT in their design team meeting discourse. This suggests that regardless of APT use in group discourse, groups made similar types of connections between and/or among epistemic elements in Conversations 1 and 2. Said another way, these findings suggest that collaborative conversational moves, as evidenced by APT, did not particularly support or impede the way groups integrated different epistemic elements into their design thinking in the design team meetings in Design Cycle 1.

5.5 Analysis of findings for Conversation 3

5.5.1 Context/Orientation

In Conversation 3 - the first design team meeting students engaged in after re-assignment to their new groups in the *Nephrotex* internship experience - interns discussed the strengths and weaknesses of the materials they tested in the first design cycle (i.e., with their prior group). Then, based on their collected findings, groups proposed, and provided justification for, five new devices to test. The median distribution of groups' (n=55) use of each conversational move type in this conversation is presented below (Figure 5.4).

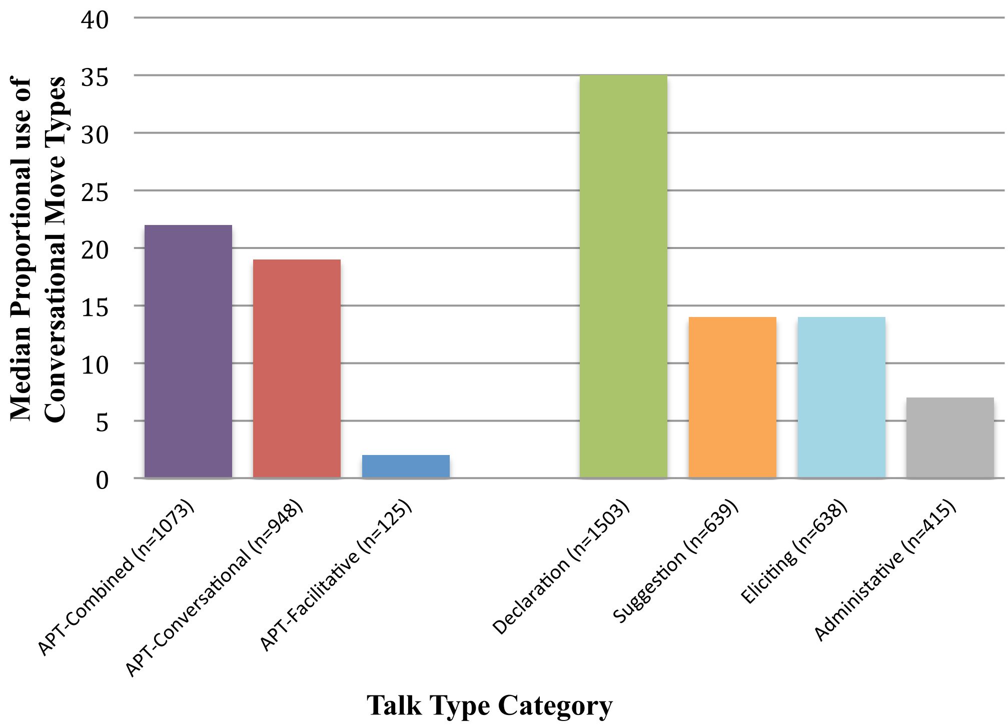

Figure 5.4. Median proportional distribution of conversational moves, by category, in design team discourse in Conversation 3 (N=4268).

This graph highlights the prominence of Declaration moves (i.e., *Present, POV, Activity, Inform*) compared to other moves types (35%, n=1503). It is worth noting that this is the only conversation when Declaration moves represent a greater proportion of student contributions than do APT moves in design meeting discourse - in all other conversations, APT moves represent between 45% and 49% of student contributions. Lastly, although the median proportion of all APT move use in this conversation was 22% (n=1073), only 2% (n=125) were APT-Facilitative moves.

5.5.2 ENA Results for Conversation 3

ENA results indicated differences in the frequency and types of connections made in Conversation 3 comparing the design meeting discourse of high and non-high APT use groups, the details of which will be described in what follows.

First, I present Figure 5.5 (below), which is a plot of the mean of the network connections for groups with differing proportions of APT use in Conversation 3 (colored squares represent mean values of each subset of APT use groups; dots represent each unique group in the subset; squares represent 95% CIs around the mean). T-tests indicated that the observed differences in the engineering discourse comparing groups that used high (red) and non-high (blue) proportions of APT were statistically significant ((*t*)-2.528, p=0.015, *d* = 0.61). Groups that used high proportions of APT in Conversation 3 scored lower, on average, on ENA dimension 2 (i.e., Consultant & Data Analysis). Cohen's effect size value (*d* = 0.61) suggests a moderate practical significance regarding differences in the discourse of groups that used high proportions of APT, compared to those that did not.

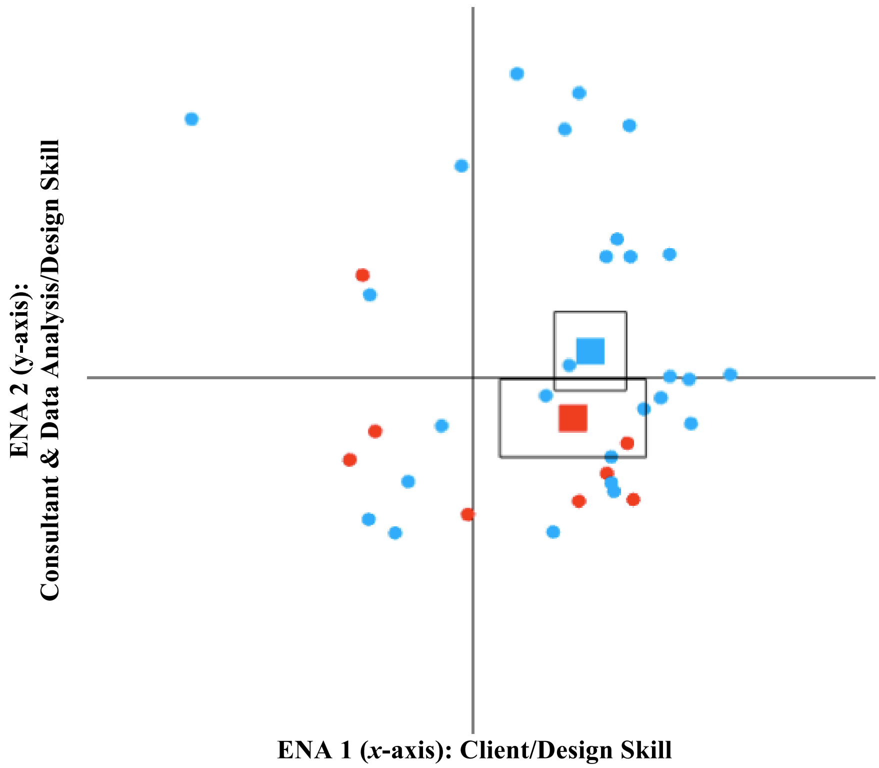

Figure 5.5. Plot of mean of network connections for high (red, n=14) and non-high (blue, n=41) APT use groups in Conversation 3.

The types of network connections that reflect the epistemic discourse of high and non-high APT use groups can be seen in the mean equiload models presented below, in Figure 5.6. A comparison of these two models suggests that groups that used high proportions of APT (in red), compared to those that did not (in blue), more frequently connected data analysis (i.e., skill) to other aspects of engineering design in their discourse. Additionally, these groups more frequently used data to justify their design decisions (i.e., epistemology). Said another way, students in these groups more often integrated the skill and epistemology of data into their design thinking during design meeting discourse. Finally, high APT use groups also more frequently connected their consultant's interests to other aspects of engineering design. That is, these groups integrated the needs, concerns, preferences, etc. of their consultants into their design thinking.

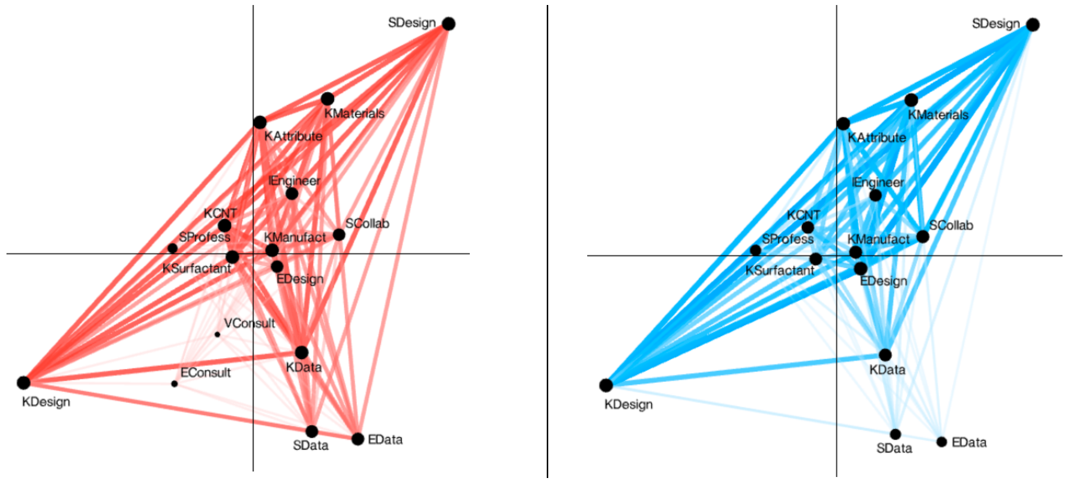

Figure 5.6. Mean network models of group discourse in Conversation 3. LEFT PANEL: high APT use groups (red, n=14). RIGHT PANEL: low APT use groups (blue, n=41).

How these two models differ - in terms of the relative strength of their connections – is emphasized in the comparative (i.e., “subtracted”) model presented below (Figure 5.7).

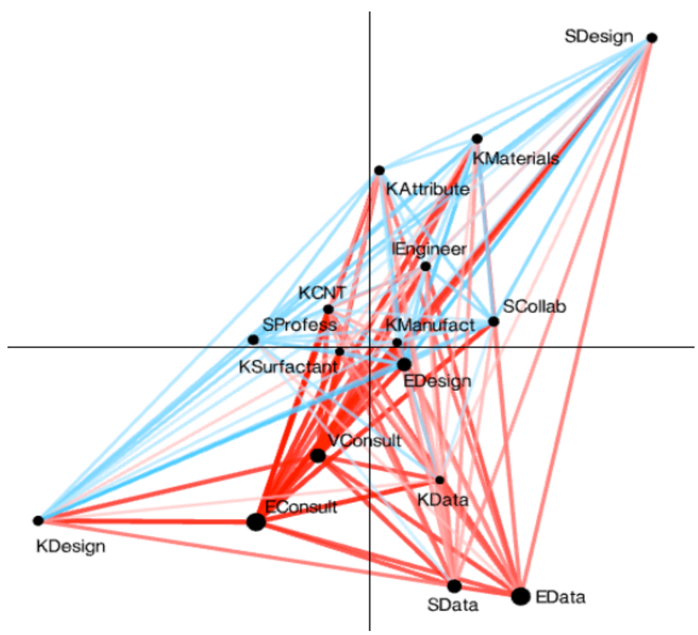

Figure 5.7. Comparative model of groups using high (red, n=14) and non-high (blue, n=41) APT in conversation 3.

Specifically, the node sizes and line weights in this model indicate how groups with high APT use, relative to non-high groups, made more and stronger connections between aspects of data analysis, the consultant, and other aspects of engineering practice. Additionally, the model shows how these groups have a denser network of connections to more epistemic elements relative to these aspects, and in particular to engineering design knowledge. This indicates that these groups repeatedly made connections between these elements more frequently. Taken together, these findings imply that groups that used high proportions of APT in their discourse *spent more time* discussing, employing and justifying their design decisions with data, in relation to the consultant's interests and engineering design knowledge, than did non-high APT use groups[32]. The effect of these more robust connections made by high APT-use groups in this conversation is that they were better able to attend to more nuanced, content-specific considerations in their design thinking as they worked collaboratively to synthesize the knowledge and understanding each group member acquired in their first group, to generate new and improved devices to meet a broader range of constraints in their new group.

5.5.3 Evidence of ENA results reflected in student discourse in Conversation 3

The relationship between more proportional use of APT moves and the greater frequency of connections in discourse among particular engineering design elements in Conversation 3 (presented above) is evidenced in student's conversational data (i.e., chat-logs). In particular, the examination of student discourse suggests that it is not that APT moves are specifically associated with particular epistemic frame elements in this

[32] ENA results also indicated that this finding persisted, though with only a moderate effect, when considering both conversations in this design cycle level (i.e., over time) ((*t*)-2.053, p=0.047, *d*=0.51).

conversation, but that connections to those elements are better integrated into student's design thinking when there is a greater use of APT moves in discursive interaction.

In what follows, I present three representative samples from the conversational data[33] of discourse in Conversation 3 (Figures 5.8-5.10). The first two are drawn from high APT use groups. For comparative purposes, the third is from a non-high APT use group. In each figure, for utterances coded as APT, the moves are highlighted in red. The corresponding epistemic coding for each utterance, if any, are presented in the right hand column – evidence of the epistemic elements of engineering design knowledge are highlighted in green, the consultant are in blue, and data analysis are in orange. In order to provide rich description of the conversational interactions that highlight the relationship between conversational moves and epistemic connections in discourse, I have broken down each sample into smaller units for the purposes of analysis.

As will be described below, the comparison of these representative samples highlights how groups with high APT use in the course of this conversation were better able to focus on critical and domain-based content connections (i.e., to the consultant and to data analysis) that resulted in more robust epistemic discourse as they worked to complete their task.

[33] Student names are pseudonyms.

Discourse samples from high APT use groups in Conversation 3

The first sample (Figures 5.8a-5.8c, below) highlights how one group's discursive use of APT extended and clarified their decision making in a way that integrated *the Consultant* into their design thinking. For instance (see Figure 5.6a), Jack seeks consensus (via the APT-Facilitative (APT-F) move, *Agree/Disagree*) about the team's design choice to focus on one device attribute, reliability, which initiates further use of APT moves in subsequent discourse. In particular, following this prompt, John elaborates on Claire and Sayid's agreements by providing an explanation in relation to engineering design about *why* the proposed attributes are the right ones (via the APT-Conversational (APT-C) move, *Explain*).

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Jack	APT-F: *Agree/ Disagree*	so do we all agree that our main goal is to focus on reliability ?	Tech. Knowledge[34] (1)
Claire	DECLARE*: POV*	Yes, I think so, followed closely by blood cell reactivity	
Sayid	APT-C: *Agree/ Disagree*	Yeah, those are important ones	
John	APT-C*: Explain*	Those two will give us the best device	Engineering Design[35]

Figure 5.8a. Chat log excerpt from a high APT use group in Conversation 3.

These exchanges are followed by Claire and Jack's justifications for these decisions (APT-C: *Share Reasoning*), which prompt Sayid to follow up with a clarifying question that ensures that the team is *connecting* their focus on their selected attribute *to what their consultant's interests/needs are* (i.e. values) (see Figure 5.8b). After Claire informs the group about what *the consultant wants* in the device, she presses Sayid to justify his choice to include CNT in the device design to obtain the necessary reliability.

[34] Indicates utterance coded for any of the following epistemic elements for technical knowledge related to device design: attribute=1, material=2, manufacturing=3, surfactant=4, CNT=5.
[35] Indicates utterance coded for knowledge, skill, *and* epistemology of design.

Student	Conversational Category: *Move*	Student Utterance	Epistemic Code(s)
Claire	APT-C: *Share Reasoning*	I think Poly(methyl methacrylate) would not work with any model we could try<->It does not have high enough flux values for any of the internal consultants and, even with such low flux values, does not significantly outdo any of the other materials in blood cell reactivity or reliability	Tech. Knowledge (1,2)
Jack	APT-C: *Share Reasoning*	We used Polyrenalate because it had high flux values. we might want to look into that.	Tech. Knowledge (1,2)
Sayid	ELICIT: *Clarify*	I agree, 11 is too low. What did the consultants say our reliability should be again?	Consultant (Values) Tech. Knowledge (1)
Claire	DECLARE*: Inform*	Reliability should be better than 5.5 hours	Tech. Knowledge (1)
Claire	ELICIT*: Pose*	what would our other parts be? something that has a very high reliability for sure	Tech. Knowledge (1)
Sayid	ELICIT: *Pose*	hydrophillic and 2% cnt?	Tech. Knowledge (4,5)

Figure 5.8b. Chat log excerpt from a high APT use group in Conversation 3.

Lastly (Figure 5.8c), after Jack agrees with the device specs put forth by Sayid (APT-C: *Agree/Disagree*), Claire seeks confirmation from him that the team's decision is *justified with regard to their consultants' interests* (APT-F: *Press for Reasoning*). Finally, Jack clarifies for the group that the issue *for the consultant* is related to cost (APT-C: *Say More*).

Student	Conversational Category: *Move*	Student Utterance	Epistemic Code(s)
Jack	APT-C*: Agree/ Disagree*	Um, 2% is rather low <->actually nevermind. i like 2%	
Claire	APT-F*: Press Reasoning*	What was our reasoning for so littel CNT in this model? Just asking because i forgot, since consultants said more CNT means more marketability<->Just cost?	Consultant (Epistemology) Tech. Knowledge (1,5)
Jack	APT-C*: Say More*	just cost yea	Tech. Knowledge (1)

Figure 5.8c. Chat log excerpt from a high APT use group in Conversation 3.

The second sample (Figures 5.9a-5.9c) reflects how another group's use of APT in discourse during a decision making process *integrated the consultant* and how they should *use data to justify* their design thinking. For example (Figure 9a), Lyla challenges Vince's proposal for how the group should proceed, highlighting that it wouldn't make sense for their next proposal with regard to the data they would obtain (APT-F: *Challenge*). This leads Tami to provide an explanation about *why* Lyla's challenge is sound in relation to their engineering design process (i.e., their use of time) (APT-C: *Explain*).

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Vince	PROPOSE: *Process*	… If you guys can all chat in your best device from your previous group then I will make a batch and send them in to Alex	Engineering Design Professionalism Collaboration
Lyla	APT-F: *Challenge*	It does not make sense to each submit our best device in the new FEEDS. We will only get results we already have.	Data Analysis Engineering Design Identity Engineer
Tami	APT-C: *Explain*	@Lyla: Correct. We need time to compare our best devices and mix and match good properties of each. This is why the 10 minute timeframe does not work.	Engineering Design

*Figure 5.9a***.** Chat log excerpt from a high APT use group in Conversation 3.

In response (Figure 5.9b), Vince puts forth a proposal for an approach the team could take that would *incorporate analysis, and justification with, data* to determine what their best devices are. This is immediately followed by Lyla's process suggestion for how they could do so. Vince assents to the proposal (ATP-C: *Agree/Disagree*) that serves as a verbal cue that the group can move forward in their process. After Eric presents details to the group about his previously tested device, Tami *integrates the consultant's interest* into their design thinking with a justification about why they should consider cost based on the standards *their consultant* has requested (APT-C: *Share Reasoning*).

Student	Conversational Category: *Move*	Student Utterance	Epistemic Code(s)
Vince	PROPOSE: *Approach*	So if we submit what we already have we will get the same results back but will also be able to compare from our older groups and then make decisions from there	Data Analysis Collaboration Identity Engineer
Lyla	PROPOSE: *Process*	Why don't we each recommend one for our material that is different from the ones previously tested	
Vince	APT-C: *Agree/ Disagree*	okay sounds good	
Eric	DECLARE: *Present*	Our best was PSF, with Relability 11, Market 500k, Flux 15, Reactivity 76.67 and cost 120	Tech. Knowledge (1,2)
Tim	ELICIT: *Clarify*	what specs Lyla	
Tami	APT-C: *Share Reasoning*	I think cost can be outweighed by marketability, I would guess that we should worry about costs being at 150 since that falls within all of the consultants standards.	Consultant[36] Tech. Knowledge (1)

Figure 5.9b. Chat log excerpt from a high APT use group in Conversation 3.

Finally (Figure 5.9c), after Tim explicitly agrees with Tami's reasoning (APT-C: *Agree/Disagree*), he asks a question of the group as to *how* (not *that*) they should design their devices, providing an *integration of the knowledge and skill of engineering design*. In response, Eric proposes that they *use data* to improve the quality of their devices and then shortly afterwards, Tami extends this to propose a process by which the group can do so, similar to Lyla's contribution early in this exchange.

[36] Indicates utterance coded for values *and* epistemology of consultant.

Student	Conversational Category: *Move*	Student Utterance	Epistemic Code(s)
Tim	APT-C: *Agree/Disagree*	i agree Tami	
Tim	ELICIT: *Process*	how do we want to go about making these new devices	
Eric	PROPOSE: *Approach*	Pick one of each of our materials, and modify our best to see if we can improve results	Design (Knowledge & Skill)
Tim	ELICIT: *Process*	Each make one using our old materials?	Data Analysis Identity Engineer Tech. Knowledge (2)
Tami	PROPOSE: *Process*	I think that sounds reasonable, and then we can submit the batch. Everyone make one device that you think will perform best using your original material.	Tech. Knowledge (2)
Eric	APT-C: *Agree/Disagree*	Let's do it	Design (Knowledge & Skill)

*Figure 5.9c***.** Chat log excerpt from a high APT use group in Conversation 3.

Discourse sample from a non-high APT use group in Conversation 3

In contrast to the representative samples from high APT use groups presented above, a review of a sample of discursive interactions from a non-high APT use group highlights how their design meeting discourse *does not* effectively integrate the consultant or data analysis into their design thinking. The following discourse sample (Figure 5.10a-d, below) is characterized by the sharing of ideas and information that go un-questioned, or taken up for more critical consideration, by the group. This results in a decision making process that attends heavily to device specifications, with little integration other epistemic elements in design thinking.

As will be shown below, for example, students in this non-high APT use group do not encourage their peers to explain their reasoning (i.e., APT-F: *Press for reasoning*), or provide any for their own (i.e., APT-C: *Share Reasoning*), in key moments about how the group should design their device. Instead, students appear to take the points of view, information and proposals put forth by their teammates at face value, and there is a limited use of signals integrating agreement about proposed directions to take in their design thinking. As a consequence, the group does not effectively integrate the critical, domain-based connections related to data analysis and the consultant into their discourse, which is ultimately reflected in an epistemic frame that is less robust compared to those reflective of the discourse of high APT use groups (presented above).

For instance (Figure 5.10a), following Jimmy and Omar's questions to the group about how they should proceed in their process (that refer to aspects of design), there is a sequence of cross-talk comprised of administrative questions (i.e., questions about what the groups is supposed to be doing) and brief declarations of information (i.e., "we found phase process worked best;" "we found vapor in my group"). At this point, Kima takes the opportunity to stand back and restate what she has heard (APT-C: *Restate*) for the benefit of the group.

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Jimmy	ELICIT: *Process*	do we want to make 5 completely new devices?	Design (Knowledge)
Omar	ELICIT: *Process*	sounds good. should we use each of our best devices???	Engineering Design
Lester	ADMIN: *Pose*	How can we have one person send them?	
Jimmy	DECLARE: *Present*	we found phase process to work the best...	Tech. Knowledge (3)
Avon	ADMIN: *Pose*	is this something we can put in the shared space	
Omar	DECLARE: *Present*	we found vapor in my group	Collaboration
Lester	DECLARE: *Present*	Phase	Tech. Knowledge (3)
Kima	APT-C: *Restate*	same phase inversion to work the best, and I saw that some other people said vapor	Tech. Knowledge (3)

Figure 5.10a. Chat log excerpt from a non-high APT use group in Conversation 3.

In the subsequent interactions in this conversation, however, students engaged in discourse that reflects weaker epistemic integration compared to high-APT use groups (i.e., the group does not integrate data analysis or the consultant), as students further present information and propose ideas for the group's design (Figure 5.10b). In particular, Kima, Jimmy, and Omar propose (i.e., PROPOSE: *Response*) what the device should include, and Lester, Jimmy, and Kima contribute more information about their prior groups' work (i.e., DECLARE: *Inform*). Kima then moves the group forward with their task and these contributions are not taken up by anyone in the group for further consideration.

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Lester	ELICIT: *Clarify*	How many CNT,	Tech. Knowledge (5)
Kima	SUGGEST: *Response*	so 2 vapor 3 phase or 3 vapor 2 phase?	Tech. Knowledge (3)
Lester	DECLARE: *Inform*	we had about 2% for most and our one with 10% did not work,,, not sure shy	
Jimmy	SUGGEST: *Response*	I would say 3 phase and 2 vapor	Tech. Knowledge (3)
Kima	DECLARE: *Inform*	and for CNT my group ranged them between 10%-15% but that was because we had hydrophilic and CNT has no effect on BCR levels	Collaboration Tech. Knowledge (4,5)
Omar	SUGGEST: *Response*	but pair it with what everyone already did.... because they were probably good devices	Engineering Design
Jimmy	DECLARE: *Inform*	we had 20% CNT	Tech. Knowledge (5)
Kima	ADMIN: *State*	okay so we just have to send what each device will be	Design (Knowledge & Skill)

Figure 5.10b. Chat log excerpt from a non-high APT use group in Conversation 3.

As a result, the team never considers the implications of the data they have. For example, Lester indicates that he is "not sure [w]hy" his group's prior device did not work and Omar makes a proposal for the group to consider, though states only that they should do so "because they were probably good devices." In neither case, do their teammates seek understanding or provide a possible connection to something in the data or to constraints in the way that, for instance, Claire (see Figure 5.8c, above) made a connection to the consultant when she "pressed for reasoning." Both of these instances reflect how *not* providing or seeking a justifying (i.e., APT-C: *Share Reasoning*; APT-F: *Press for Reasoning*) or making an effort to explain something (i.e., APT-C: *Explain*), for example, may have impeded the team's integration of data or the consultant into their design thinking at key moments in their discourse.

Next (see Figure 5.10c, below), Jimmy clarifies that the group has made a decision on device specifications (APT-F: *Revoice*), which is confirmed by Lester. This is quickly followed by an additional clarification-confirmation exchange between Kima and Omar about what they are supposed to be doing. However, rather than seeking justification about why, for example, using "3 phase and 2 vapor" may make sense in terms of the data they have at hand or their consultant's interests, the group moves forward after Lester prompts the group with a process question.

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Jimmy	APT-F: *Revoice*	so are we doing 3 phase and 2 vapor correct?	Tech. Knowledge (3)
Lester	DECLARE: *Inform*	Yes	
Kima	ELICIT: *Clarify*	and the strengths of each material?(our best one)	
Omar	DECLARE: *Inform*	correct	
Lester	ELICIT: *Process*	Who wants to go first?	

Figure 5.10c. Chat log excerpt from a non-high APT use group in Conversation 3.

Lastly, the group starts to make suggestions and present their opinions about what the group should include in their device design. This reveals two additional discursive interactions when richer epistemic integration did not occur (Figure 5.10d, below). For instance, Jimmy proposes to "change the CNT %," and Kima agrees. However, as before, there is no effort made to understand why changing CNT % may or may not be a good design choice. Another interaction worth highlighting can be seen when Lester expresses his opinion (i.e., DECLARE: *POV*) that "CNT is fairly safe and would make a good difference." Although Jimmy provides a blanket agreement (APT-C: *Agree/Disagree*), neither Lester nor his teammates seek to integrate the consultant's interests at this point as to why or how safety may matter, something that could have been attained through the use of more collaborative moves, as was evidenced by the high APT use groups.

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Avon	SUGGEST: *Response*	i will go with pmma <->vapor process	Tech. Knowledge (2,3)
Lester	ELICIT: *Process*	Great, do you think there are any changes you want... or to try<->Or should we all choose our best one?	
Avon	DECLARE: *POV*	maybe just % carbon nanotube?	Tech. Knowledge (5)
Omar	SUGGEST: *Process*	I'm thinking best one	
Jimmy	SUGGEST: *Response*	mine was pes-pvp. phase process. hydrophilic. 20%<->If you guys want, we can change the CNT %...	Tech. Knowledge (3,4,5)
Kima	APT-C: *Agree/Disagree*	okay change CNT	Tech. Knowledge (5)
Jimmy	ELICIT: *Clarity*	which worked the best for everyone?	
Lester	DECLARE: *POV*	I think CNT is fairly safe and would make a good difference in mine	Tech. Knowledge (5)
Jimmy	APT-C: *Agree/Disagree*	I agree with @Lester	

Figure 5.10d. Chat log excerpt from a non-high APT use group in Conversation 3.

Summary of representative samples of groups with differing levels of APT use in Conversation 3

As presented in the representative samples above, groups that used more APT in their discourse yielded more critical content connections (i.e., an integration of data analysis and the consultant into students' design thinking). Also, the use of higher degrees of APT in student discourse resulted in a richer discussion of findings and information that included implications for their designs and/or explained the thought or decision-making process of their groups. Additionally, the discourse of these groups is more interactive as evidenced by students' efforts to gain clarity and reach consensus about the efficacy of design choices.

In contrast, the discourse of the non-high APT use group reflects conversational interaction that yields no connections in their discourse with regard to: (1) what their prior test results (i.e., data) may suggest for the new group's designs, and what may or may not be important and why about these results; or (2) how their consultant's needs/interests should be considered to justify their forthcoming design decision. This highlights moments in this group's discourse when the integration of data analysis or the consultant into their design thinking did not occur, as it did in high APT use groups through, for example, more use of *Share Reasoning, Say More, Explain, and Challenge* moves. Said another way, these data show that high APT use in Conversation 3 discourse facilitated groups' ability to focus on critical connections in their conversations, which suggests that high use of APT moves in discourse was a mechanism that led to a more integrated engineering epistemic frame, compared to groups that used non-high degrees of APT.

5.5.4 Group level characteristics associated with APT use in Conversation 3

ENA was also conducted to test whether group-level characteristics were associated with the types and frequencies of epistemic connections groups made in relation to level of APT use in discourse. ENA results indicated that in this design meeting (Conversation 3) there is a strong association between the experience level of the group (i.e., *NOVICE*) and the types and frequencies of epistemic connections made in relation to the level of APT use in discourse.

In particular, among groups with *high* APT use (Figure 5.11, below, left panel), Novice groups had lower average scores on ENA dimension 1 (i.e., Client/Design Skill) compared to Advanced groups ((t)-2.379, p=0.038, d = 0.97). This suggests that Novice groups with high APT use more frequently integrated their client's interests into their design thinking than did Advanced groups. Also presented in Figure 5.11 (right panel) is a comparative equiload model indicating how Novice groups with high APT use (in purple), relative to Advanced groups, made more and stronger connections between these, and other, epistemic elements in their discourse (including the consultant, engineering design knowledge and skill, and data (knowledge, skill, and epistemology).

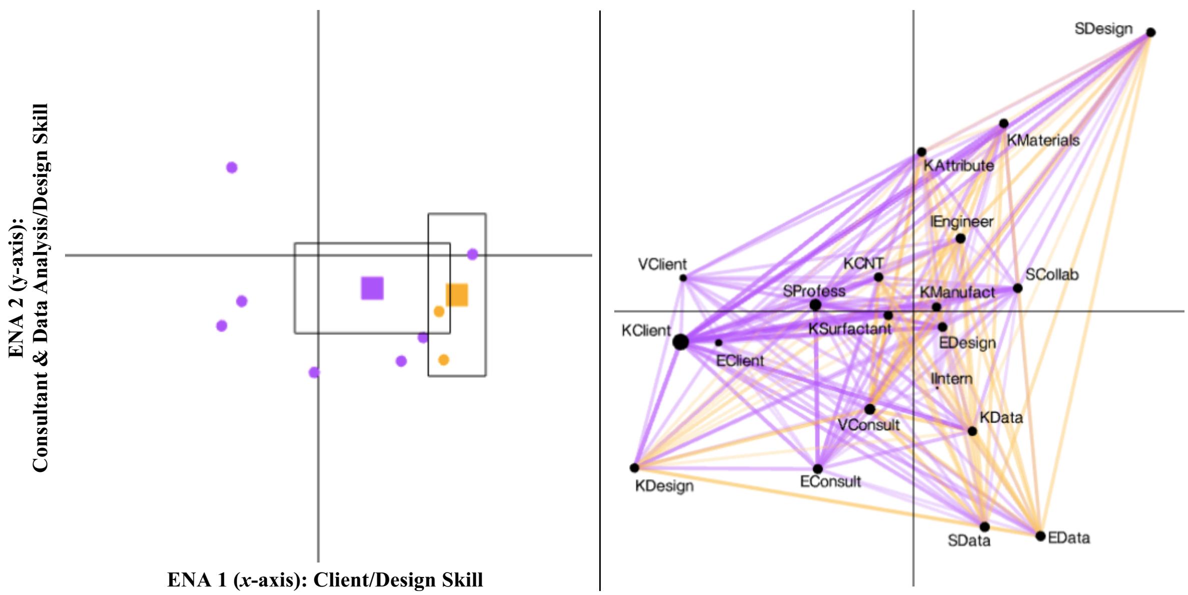

Figure 5.11. LEFT PANEL: Plot of mean of network connections in for Novice (purple, n=10) and Advanced (orange, n=4) groups with high APT use in Conversation 3. RIGHT PANEL: Comparative model of discourse for Novice and Advanced groups with High APT use in Conversation 3.

Among groups with *non-high* APT use (Figure 5.12, below, left panel), Novice groups had lower average scores on ENA dimension 2 (i.e., Consultant/Design Skill) compared to Advanced groups ((t)-2.248, p=0.038, d = 0.82). This implies that these Novice groups more frequently integrated their consultant's interests into their design thinking than did Advanced groups. Also presented in Figure 5.12 (right panel) is a comparative equiload model indicating how Novice groups with non-high APT use (in purple), relative to Advanced groups, made more and stronger connections between these, and other, epistemic elements in their discourse (including the client and engineering design knowledge and skill).

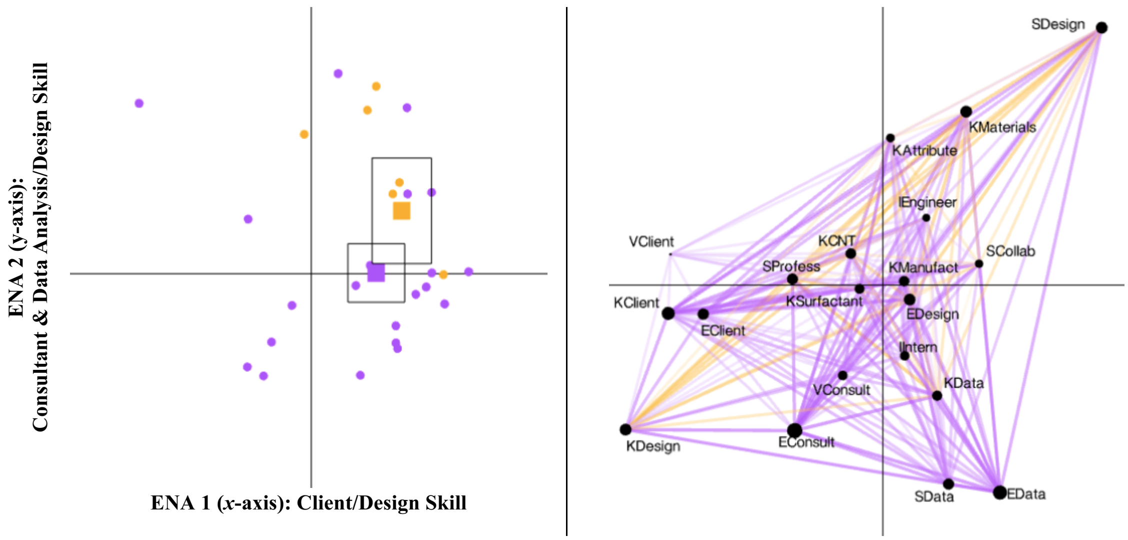

Figure 5.12. LEFT PANEL: Plot of mean of network connections in for Novice (purple, n=30) and Advanced (orange, n=11) groups with non-high APT use in Conversation 3. RIGHT PANEL: Comparative model of discourse for Novice and Advanced groups with non-High APT use in Conversation 3.

These finding suggest that, regardless of the degree of APT in design team meeting discourse in Conversation 3, Novice groups had richer networks of connections that reflected a stronger integration of the client and/or the consultant into their design thinking, whereas Advanced groups more frequently made connections between the skill of engineering design and other epistemic elements. The fact that Advanced groups had less robust networks than did Novice groups may indicate that APT-style contributions in discourse were not particularly helpful for Advanced groups with regard to whether they made connections between these epistemic elements, in *this* conversation. It is also possible that the more experienced students may have merely talked less about the consultant and the client. Said another way, it is possible that Novice students wrestled more with design implications related to the consultant and the client, in this conversation, and that Advanced students were able to do so more succinctly or intuitively.

No associative differences were found regarding the use of APT and the other group-level characteristics of gender balance, average level of confidence, commitment, and self-efficacy, or contribution equality. This suggests that group differences with regard to these characteristics are unrelated to the use of APT in design meeting discourse.

5.5.5 Summary of Conversation 3 Findings

In summary, my analysis of the ENA results and qualitative review of utterance data presented above found that groups that used more collaborative conversational moves in Conversation 3, as evidenced by APT, also more frequently integrated *the consultant* (i.e., his/her needs, interest, and expectations) and *data analysis* (i.e., knowledge, skill, and epistemology) into their design thinking in Conversation 3. This suggests that there was a relationship between a group's greater overall use of APT moves, as a proportion of all moves, in Conversation 3 and students' contributions in these groups that made more frequent and stronger connections to these particular aspects of domain-specific discourse. Relatedly, my analysis also found that Novice students, on average, integrated these epistemic elements into their design thinking more so than did Advanced students, with regard to APT use.

Finally, my analysis found that the effects of APT in design team meeting discourse reported above were different in Conversation 4, which will be presented in the next section. As will be shown, the findings are consistent with regard to how APT was related to the integration of design constraints, though they differ in a subtle way. In particular, whereas a greater use of APT in group discourse was related to considering the constraints imposed by *the consultan*t in Conversation 3, a greater use of APT in Conversation 4 was related to considering constraints related to the needs and interests of *the client*.

5.6 Analysis of findings for Conversation 4

5.6.1 Context/Orientation

Conversation 4 is the final design team meeting groups engage in during the *Nephrotex* internship. In this conversation, interns discussed the results of the five prototype devices submitted for testing in FEEDS at the end of their last meeting (Conversation 3). In light of these results, groups were tasked with considering all of the devices they'd tested over the course of the internship in order to select, justify, and submit a final prototype for evaluation and presentation. It is worth noting that of the conversations in the sample, Conversation 4 was the briefest by almost 50% - on average, discourse in this conversation was comprised of 38 utterances compared to 74 for Conversation 1, 84 for Conversation 2, and 79 for Conversation 3.

The median distribution of groups' (N=55) use of each conversational move type in this conversation is presented below (Figure 5.13). This graph highlights how APT moves characterized almost half (47%, n=958) of all utterances in this conversation and of those moves, 6% (n=162) were APT-Facilitative. Although still representing a small overall distribution, APT-Facilitative moves were three times the proportion found in Conversation 3 (6% vs. 2%).

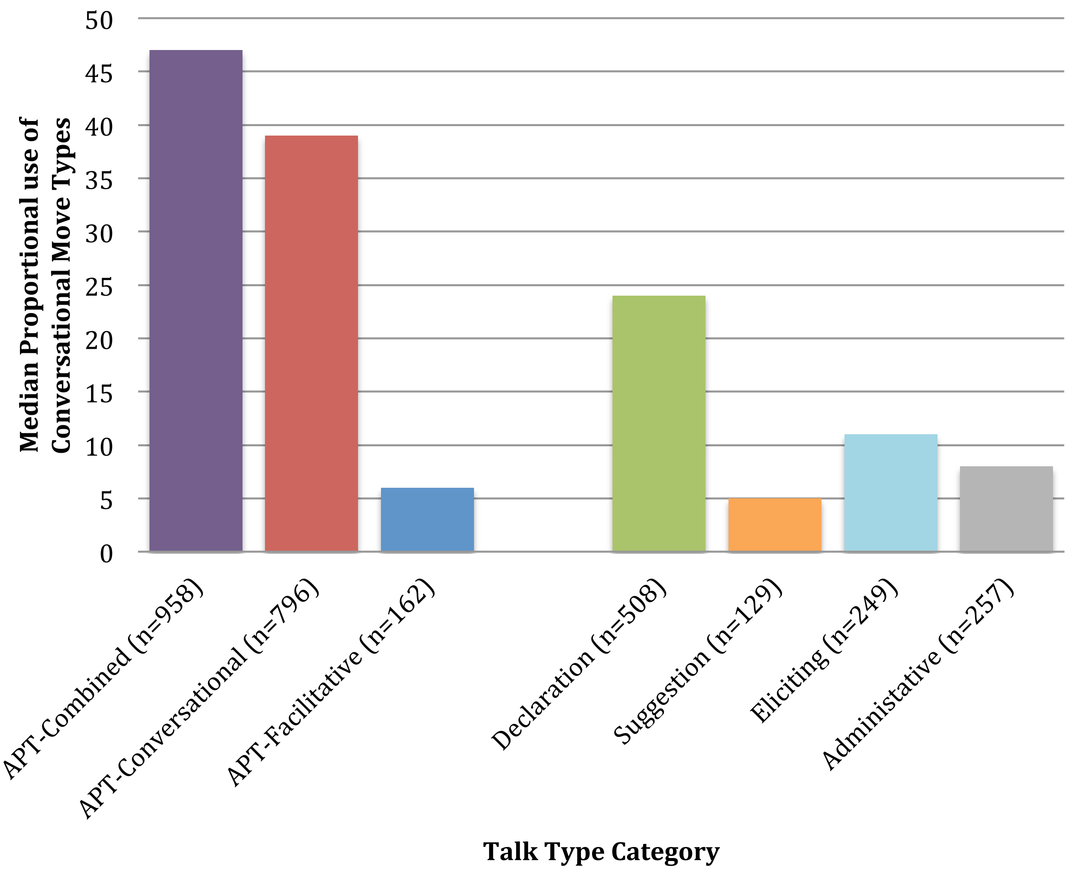

Figure 5.13. Median proportional distribution of conversational moves, by category, in design team discourse in Conversation 4 (N=2101).

5.6.2 ENA results for Conversation 4

ENA results indicated differences in the frequency and types of connections made in Conversation 4 comparing groups that used higher and lower proportions of APT in design meeting discourse. The details about these findings, and how they are different from those found in my analysis of Conversation 3, are presented below.

First, I present Figure 5.14 (below), which is a plot of the mean of the network connections for those groups with differing APT use in Conversation 4. T-tests indicated that the observed differences in engineering discourse comparing groups that used higher (red) and lower (blue) proportions of APT was statistically significant ((t)-2.882, $p=0.006$, $d = 0.79$). Groups that used higher proportions of APT in Conversation 4 scored lower, on average, on ENA dimension 1 (Client/Design Skill). Cohen's effect size value ($d = 0.79$) suggests a strong practical significance regarding how groups that used higher proportions of APT, compared to those that did not, are different with regard to their epistemic discourse.

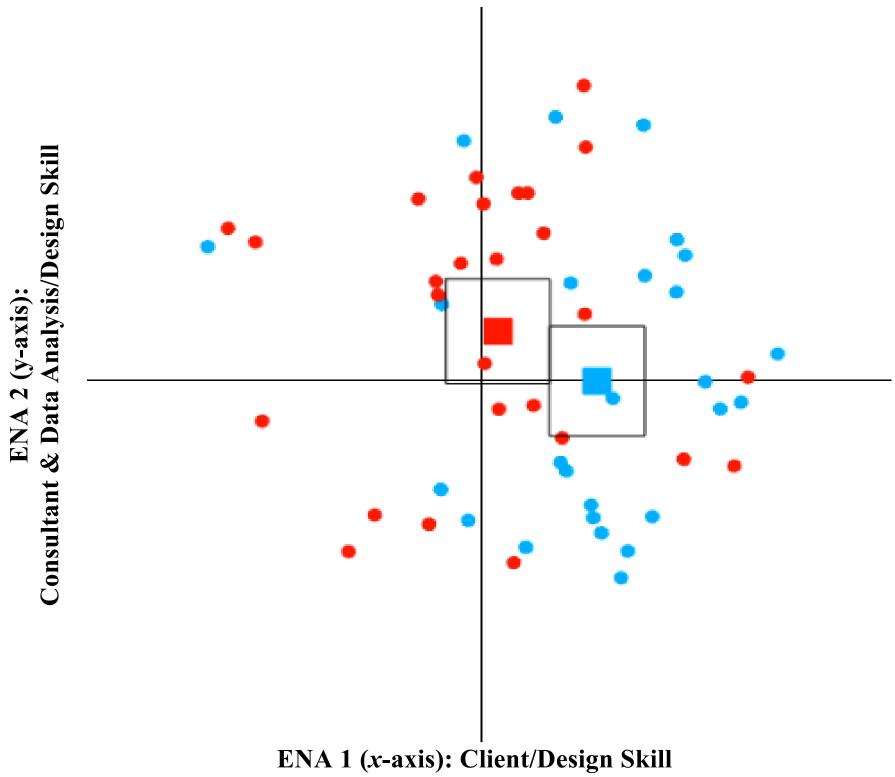

Figure 5.14. Plot of mean of network connections for higher (red, n=28) and lower APT (blue, n=27) use groups in Conversation 4.

The types of network connections that reflect the epistemic discourse of higher and lower use APT use groups can be seen in the mean equiload models presented below in Figure 5.15. These models suggest that groups that used higher proportions of APT (in red), compared to those that used lower (in blue), more frequently connected their knowledge of the client/patient's wellbeing (i.e., health, comfort and/or safety) to other aspects of engineering design. These groups also more frequently justified their design decisions (i.e., epistemology) in relation to the client/patient's wellbeing. Said another way, students in these groups more often integrated considerations of the health, comfort and/or safety of their clients/patients into their design thinking during design meeting discourse.

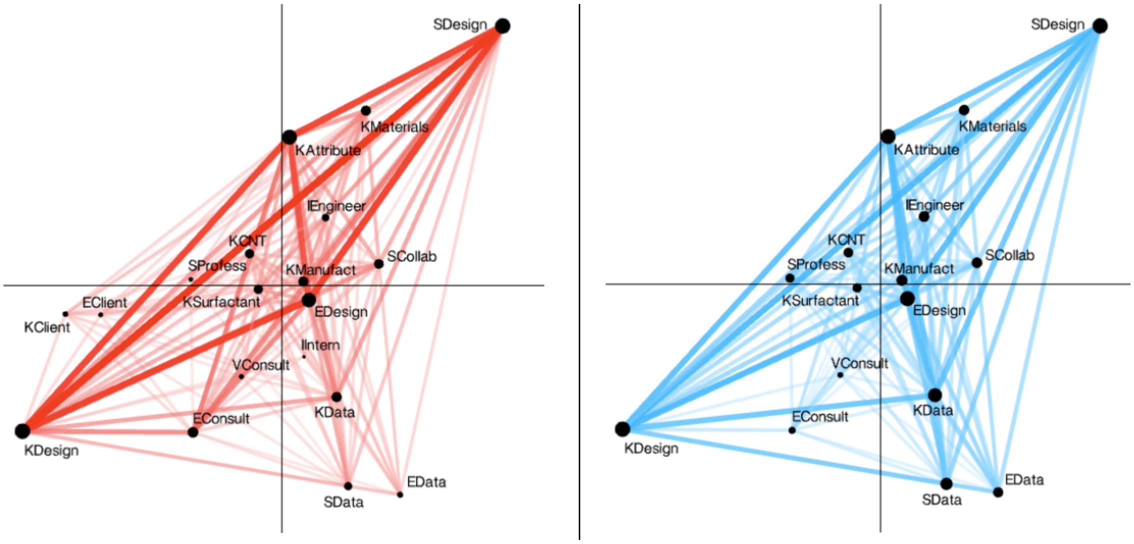

Figure 5.15. Mean network models of groups' discourse in Conversation 4. LEFT PANEL: Higher APT use groups (red, n=28). RIGHT PANEL: Lower APT use groups (blue, n=27).

Given the similarity of these models with regard to the density of their connections, I present a comparative network model (Figure 5.16, below) to illuminate further differences in the relative strength of their connections.

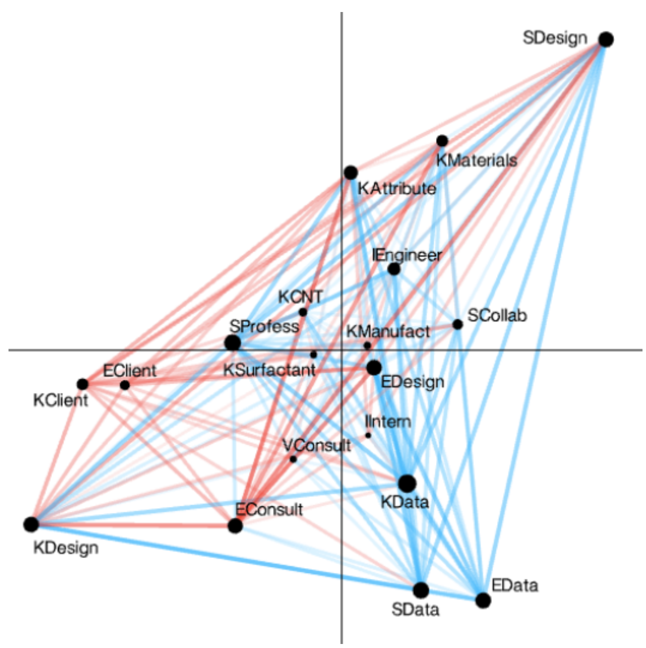

Figure 5.16. Comparative model of groups using higher (red) and lower (blue) APT in Conversation 4.

In particular, the node sizes and line weights in this model highlight how groups with higher APT use, relative to lower use groups, made more and stronger connections between aspects of the client (*knowledge* and *epistemology*) and other aspects of engineering practice in this conversation. This finding implies that groups that used higher proportions of APT in their discourse *spent more time* discussing, and justifying, their design decisions in relation to client's needs, than did lower APT use groups. The implication of higher APT-use groups more frequently making such connections is that they were better able to attend to this important design constraint as they worked collaboratively at a key phase of their design process, namely, when they were finalizing their "best" design for submission.

It is worth noting two other differences highlighted in this model. First, higher APT use groups (in red), on average, persisted in making stronger connections to the consultant, as was found in Conversation 3 (reported in the previous section). Second, in contrast to the findings reported for Conversation 3, it was *lower* APT use groups (in blue) that, on average, more frequently integrated data analysis into their design thinking. However, in both instances, the observed difference in the frequency of these connections in discourse was not statistically significant (i.e., on the y-axis). This suggests that the degree to which higher and lower use APT groups integrated the consultant and data analysis into their design thinking was not substantively (i.e., semantically) different, even if it if was more frequent overall, as will described shown below. That is, collaborative conversational moves did not particularly support or impede whether students made connections to these epistemic elements in their discourse in Conversation 4.

The key difference between these findings and those for Conversation 3 is that they imply that the use of APT was salient with regard to *which* design constraint was better integrated into a group's design thinking. In particular, the shift in the effect of increased APT use from the *consultant* and *data analysis* in Conversation 3 to the *client* in Conversation 4 suggests that the effects of APT varied as a function of the focal work in each design meeting. For instance, in Conversation 3, groups were building their knowledge and integrating the findings collected about the variety of materials and consultants' interests that students' prior groups worked with (i.e., in Design Cycle 1) in order to test new, and more complex, devices. It therefore makes sense that the consultant and data analysis were better integrated through more collaborative interaction in this conversation. In Conversation 4, however, groups were expected to consider the results of how these newly tested devices performed in order to come to consensus on a final device that would best satisfy the design constraints with regard to the interests of the consultants *and* the needs of the client. In this conversation, greater or lesser use of APT was not related to how well groups integrated the consultant and data analysis in their design thinking. This makes sense because groups have already synthesized their knowledge of prior performance data and understandings of various consultants' interests prior to this conversation. Instead, my findings suggest that increased collaborative interaction in Conversation 4 served a different function in the final design meeting of the simulation. That is, it supported groups' surfacing and accounting for the health and well being of the client in the specifications for their final device submission in the simulation.

5.6.3 Evidence of ENA results reflected in student discourse in Conversation 4

The relationship between more proportional use of APT moves and the greater frequency of connections in discourse to *the client* (i.e., epistemology and knowledge) in Conversation 4 is evidenced in student's conversational data (i.e., chat-logs). In particular, the examination of student discourse suggests that in this conversation, connections to these elements are better integrated in student's design thinking when there is a greater use of APT moves in discursive interaction in general, and in particular, two APT moves were specifically associated with the integration of the client's safety, well-being, etc. in student discourse (i.e., APT-C: *Explain* and *Share Reasoning*). In what follows, I present three representative samples of discursive interaction in Conversation 4 (Figures 5.17-5.19). The first two are drawn from higher APT use groups, and the third, for comparative purposes, is from a lower APT use group.

As will be described below, the comparison of these representative samples highlights how groups with higher APT use in the course of this conversation were better able to focus on critical and domain-based content connections to *the client* in a way that resulted in more nuanced epistemic discourse as they worked to complete their task.

Discourse samples from higher APT use groups in Conversation 4

The first conversational sample (Figures 5.17a-d, below) features the discursive interactions of a higher APT use group. The sample highlights how this group integrated *the client*, as well as data analysis and the consultant's interests, into their design thinking through efforts to *explain why* the ideas of their teammates are good ones for the team's decisions.

For instance, this conversational exchange begins (Figure 5.17a) with an effort by Dale to affirm that the group has come to consensus about their final decision regarding the device the team will use in their final submission (APT-F: *Revoice*). However, after Andy confirms (APT-C: *Agree/Disagree*), Dale challenges this decision, noting that he thinks a different device is better (APT-F: *Challenge*). This syntactic move initiates a semantically rich series of interactions, discussed below, among the team about the pros and cons of their final decision that integrates data analysis, engineering design, the consultant and *the client* into the team's design thinking.

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Dale	APT-F: *Revoice*	So we all decided on device 3 right?	Design (Knowledge & Skill)
Andy	APT-C: *Agree/Disagree*	sure	
Dale	APT-F: *Challenge*	I think device two is better after doing the assignment for last week though	Design (Knowledge & Skill)

Figure 5.17a. Chat log excerpt from a higher APT use group in Conversation 4.

Following Dale's challenge, Lucy presents her option that device 3 is her choice (Figure 5.17b, below). Harry, though, not only agrees with Dale's opinion about device 2, but explains *why* it is important by raising the issue of *the client's health* (APT-C: *Explain*). Dale then indicates that he agrees with Harry's explanation (APT-C: *Agree/Disagree*). Next, Lucy explains her position regarding the use of device 3 (i.e., that it is the best "overall"), referring to the data about the devices (APT-C: *Explain*). Harry and Dale both challenge her position by presenting evidence about *the consultant's interests* and potential limitations to the design of that device (APT-F: *Challenge*).

Student	Conversational Category: *Move*	Student Utterance	Epistemic Code(s)
Lucy	DECLARE: *POV*	i say deviece 3	
Harry	APT-C: *Explain*	I agree also because 2 has a much lower flux which is pretty important because it can physically affect the health of the patient	Client (Knowledge & Epistemology) Tech. Knowledge (1)
Dale	APT-C: *Agree/Disagree*	@Harry. I agree	
Lucy	APT-C: *Explain*	yeah. all of the devices are good, and some are better in some attributes than others, but overall #3 is the best. its kinda like the average of the results	Data Analysis Engineering Design Tech. Knowledge (1)
Harry	APT-F: *Challenge*	3 kind of has a high BCR though compared to where many consultants want it	Consultant (Knowledge)
Dale	APT-F: *Challenge*	@Lucy. The only attribute in device 3 was marketability and cost	Design (Knowledge) Tech. Knowledge (1)

Figure 5.17b. Chat log excerpt from a higher APT use group in Conversation 4.

These syntactic challenges lead the students to better explain their arguments for one device over the other (Figure 5.17c). For instance, Dale follows up his own challenge by providing a justification for why "device 2" is a better choice, noting how it satisfies *the consultant's parameters* (APT-C: *Share Reasoning*). He also clarifies previously presented data about the limitation of each device under discussion (APT-C: *Restate*). To try to persuade her teammates, Lucy then continues to explain her position by discussing the implications of the data results they have in relation to the device design (APT-C: *Explain*).

Student	Conversational Category: ***Move***	Student Utterance	Epistemic Code(s)
Dale	APT-C: *Share Reasoning*	however device 2's cost satisfies internal consultants<->the only thing that device 2 lack in is marketability<->the attribute that device 3 lacks is BCR	Consultant (Epistemology) Engineering Design Tech. Knowledge (1)
Lucy	DECLARE: *Inform*	@Harry. i dont think the consultants specified a number that they wanted...	
Dale	APT-C: *Restate*	Also, device two's cost satisfies internal consultant rates<->So it comes down to device 2 lacking in marketability and device 3 lacking in bcr levels	Data (Skill & Knowledge) Design (Knowledge & Skill) Tech. Knowledge (1)
Lucy	APT-C: *Explain*	@Dale. the higher the cnt, the better the flux and reliability. but theres really no point to go higher than 10% cnt because thats where you get the best results for the price <-> device 3 isnt lacking in bcr levels....its bcr is still a good number<->its just not 5/5	Data Analysis Design (Knowledge & Skill) Tech. Knowledge (1,5)

*Figure 5.17c***.** Chat log excerpt from a higher APT use group in Conversation 4.

Dale, however, remains un-persuaded and explains to Lucy that one attribute (i.e., BCR) has a more important effect *on the patient* (APT-C: *Explain*) and refers to his notes about the interests of *the consultants* (Figure 5.17d, below). Harry then explains why he continues to agree with Dale's position (APT-C: *Explain*), again integrating the needs *of the client* into his design thinking. At this point, Lucy does not continue to try to persuade her team to think differently, but merely expresses her opinion about the data levels they are using as decision criteria (DECLARE: *POV*).

Student	Conversational Category: ***Move***	Student Utterance	Epistemic Code(s)
Dale	APT-C: *Explain*	According to my attribute rankings, I think that BCR (directly affecting the patient) is more important than the marketabilty	Client (Knowledge) Design (Knowledge & Skill) Tech. Knowledge (1)
Dale	DECLARE: *Inform*	@Lucy. I have in my notes that internal consultants want a bcr level low at under 45 nano grams.ml<->For Rao it's 45 nano grams/ml and for Anderson it's 55	Consultant (Knowledge) Identity Intern Tech. Knowledge (5)
Harry	APT-C: *Explain*	I agree lets go with the lower BCR because patients will pay more money to be less affected by the treatment	Client (Knowledge & Epistemology)
Lucy	DECLARE: *POV*	i think 54.44 is perfectly fine. you cant have the best numbers for all of them..	Data (Knowledge & Epistemology)

*Figure 5.17d***.** Chat log excerpt from a higher APT use group in Conversation 4.

The second representative sample from a higher APT use group (Figures 5.18a-c, below), reflects how another group's use of APT in discourse during a decision making process integrated *the client* into their design thinking as the group came to consensus about their final device specifications. This sample opens (see Figure 18a, below) with Carrie stating that she thought that a teammates' device had good results (in terms of their consideration of it for final device selection).

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Carrie	DECLARE: *POV*	i thought the Saul device had good results	Data (Knowledge) Design (Knowledge)
Quinn	APT-C: *Explain*	@Carrie. Yeah, i agree too. Saul's had a very low flux rate<->oh wait, i mean a low blood cell rate	Tech. Knowledge (1)
Carrie	DECLARE: *POV*	also the Max device had good results, not including the high price	Data (Knowledge) Design (Knowledge) Tech. Knowledge (1)
Nicholas	APT-C: *Share Reasoning*	I liked the PES-PVP model. It had a decent flux-reliability-reactivity blend. The reactivity for Saul's model may be low, but the low flux and reliability will mean a longer treatment time for the patient, which would negate the effect of the great reactivity.	Client (Knowledge) Tech. Knowledge (1)
Max	APT-C: *Share Reasoning*	Nicholas's might be better though because the blood cell reactivity is up to standards for both consultants and it is less money	Consultant (Epistemology)
Quinn	APT-C: *Explain*	im split between the Saul, Max, and Nicholas model only because their blood cell reactivity is so low	Tech. Knowledge (1)

Figure 5.18a. Chat log excerpt from a higher APT use group in Conversation 4.

Quinn agrees with Carrie's assessment by providing an explanation in terms of the device attribute (i.e., low blood cell reactivity) (*APT-C: Explain*). Next, Carrie puts forth another opinion about a different design, again based on its results (i.e., Max's design). Then Nicholas presents a different opinion that he justifies by integrating how it would impact *the patient* (APT-C: *Share Reasoning*). Max adds additional justification as to why this would be a good model by integrating how it would meet *the consultant's* standards as well (APT-C: *Share Reasoning*). After hearing his points, Quinn steps back to express a concern about why the device specification may be too low (APT-C: *Explain*).

The next series of exchanges ground the team's focus in relation to engineering design practices (Figure 5.18b, below).

Student	Conversational Category: *Move*	Student Utterance	Epistemic Code(s)
Quinn	PROPOSE: *Process*	we should rank the attributes	Design (Knowledge & Skill) Tech. Knowledge (1)
Saul	PROPOSE: *Approach*	all of the designs are going to be weak in one area at least, we just need to determine which area is the least important	Engineering Design
Saul	DECLARE: *Present*	marketability and BCR were ranked 1,2 respectively in my previous group	Design (Knowledge & Skill) Collaboration Tech. Knowledge (1)
Nicholas	APT-C: *Share Reasoning*	I believe that flux is most important, followed closely by reliability. These two mean the patient spends less time in treatment. Reactivity comes third, but its effects can be negated by the first two. Marketability comes 4th, and cost 5th.	Client (Knowledge) Tech. Knowledge (1)
Max	APT-C: *Share Reasoning*	the least important is marketability because it depends on all the other aspects of the device	Design (Knowledge & Epistemology) Tech. Knowledge (1)
Carrie	DECLARE: *POV*	i think flux and reliability 1 and 2 also	Tech. Knowledge (1)
Nicholas	APT-C: *Share Reasoning*	I think cost is least important, because it doesn't seem to have any effect on marketability. Look at our most expensive one: it has the highest marketability.	Tech. Knowledge (1)

*Figure 5.18b***.** Chat log excerpt from a higher APT use group in Conversation 4.

Quinn immediately follows up his concern (from above) by proposing a process the group should use to make their decision (i.e., rank the attributes). This proposal is extended by a recommendation from Saul about the approach the group could use to do so (i.e., determining what is least important). After Saul presents how device specifications were ranked in his previous group, Nicholas indicates his preferences in ranking and justifies his position in relation to how the decisions will impact *the patient experience* (APT-C: *Share Reasoning*). Next Max shares a rationale for why Saul's ranking may not be effective (APT-C: *Share Reasoning*) immediately followed by Carrie expressing her opinion about the top two rankings presented by Nicholas. At this point, Nicholas provides further clarity about why he ranked things the way he did, highlighting the relationship between cost and marketability (APT-C: *Share Reasoning*).

The last part of this interaction sample (Figure 5.18c, below) shows the group coming to agreement about how they will rank the aspects of their device for final submission.

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Max	DECLARE: *POV*	i think flux and blood cell reactivity then reliability	Tech. Knowledge (1)
Quinn	DECLARE: *POV*	i believe reliabiltiy should be ranked high, but im looking at the consultant requests and they want above 5.5 which all of ours are. so should we ignore reliability?	Consultant (Values) Design (Knowledge) Tech. Knowledge (1)
Carrie	DECLARE: *POV*	yeah or put it third which is what MAx said	
Quinn	APT-C: *Agree/Disagree*	i agree	
Max	DECLARE: *Present*	The marketability is very driven by the blood cell reactivity i used to have 87 bcr in my device and i changed it to biological<->it used to have a marketability of 700,000	Design (Knowledge & Skill) Tech. Knowledge (1,4)
Saul	APT-C: *Share Reasoning*	i think BCR is more important than flux since BCR directly impacts discomfort of the patient where as flux just deals with how quickly the procedure takes. Why have an uncomfortable quicker procedure when you can have a comfortable procedure that lasts a bit longer	Client (Knowledge & Epistemology) Tech. Knowledge (1)
Max	APT-C: *Agree/Disagree*	i agree with Saul	
Carrie	APT-C: *Agree/Disagree*	same here	
Saul	APT-C: *Agree/Disagree*	i agree that cost should be least important	Tech. Knowledge (1)

Figure 5.18c. Chat log excerpt from a higher APT use group in Conversation 4.

Following from the previous justifications presented by Nicholas, three students (Max, Quinn and Carrie) all clarify their positions about the rankings (i.e., DECLARE: *POV*), closing with Quinn's agreement (APT-C: *Agree/Disagree*) that signals to the group that he and Carrie are behind what Max shared. Next, Max presents detailed specifications to the group, followed by Saul integrating the comfort of *the patient* as justification for why BCR is more important than flux (APT-C: *Share Reasoning*). This exchange closes with a series of final agreements that signal consensus about the team's design decisions (APT-C: *Agree/Disagree*).

Discourse sample from a lower APT use group in Conversation 4

In contrast to the representative samples from higher APT use groups presented above, a review of a sample of discursive interactions from a lower APT use group highlights how their design meeting discourse *does not* integrate the client into their design thinking in key moments of discourse (Figures 5.19a-d). As will be shown below, with one exception, the only type of APT contribution evident in this group's interactions are *Agree/Disagree* moves. Although group members consistently signal agreement with the ideas put forth by others, students do not engage in discourse that considers how their design decisions relate to the well being, safety, or health of the client (i.e., the patient). Nor do they consider *why* their device is the best they can come up with beyond detailing it's specifications.

A comparison of this sample of discourse next to those from groups with higher APT use (above), shows that the primary types of syntactic contributions in this conversation are: (1) declaration moves that characterize student's opinions, presentations of findings, or informing others about the details of their device specifications; or (2) eliciting moves used by students to seek more specific information from teammates. It is also important to note that the sample of discourse that follows is a record of the *entirety* of the group's conversation.

For instance, Daryl initiates the conversation (see Figure 5.19a, below) by asking his teammates if they should decide on their best device (which is the group's task in this room).

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Daryl	ELICIT: *Process*	so should we decide which device is the best?	Engineering Design
Rick	ELICIT: *Pose*	yeah what are your thoughts?	
Daryl	DECLARE: *POV*	i think the Pes-Pvp; Biological; Phase; 10% was the best device	Design (Knowledge & Epistemology) Tech. Knowledge (3,4)
Rick	APT-C: *Explain*	yeah i would probably agree or maybe the polyrenalate device but that one has too high of blood cell reactivity	Design (Knowledge & Skill) Tech. Knowledge (2)
Glenn	APT-C: *Agree/Disagree*	I would agree	
Maggie	DECLARE: *POV*	@Rick. I agree. We also can choose a device that any of us created previously that we think is better. But, from our group batch, I think the Pes-pvp device is best.	Engineering Design Collaboration
Daryl	APT-C: *Agree/Disagree*	yes, that is the best one that i have out of all the devices i have results for	Data (Knowledge & Epistemology) Design (Knowledge & Epistemology)
Glenn	DECLARE: *Inform*	None of the devices from my previous team could hold a candle to the device Daryl suggested	Design (Knowledge & Skill) Collaboration Identity Engineer
Rick	DECLARE: *Inform*	same for me	

Figure 5.19a. Chat log excerpt from a lower APT use group in Conversation 4.

After Rick asks Daryl what he thinks, Daryl shares his opinion regarding what he thinks their best device is, though does not include any rationale as to why. Rick, though, provides an explanation as to why he thinks Daryl's idea may be a good one through comparison with another possibility (APT-C: *Explain)*, about which Glenn agrees. Maggie also signals her agreement with the group's thinking thus far and adds some additional opinions of her own, followed by Daryl agreeing (APT-C: *Agree/Disagree)*, again, that the original device he suggested is the best. Glenn and Rick then inform the team that their prior team's devices were inferior to the current device the group is considering. As can be seen, at no point in this sequence of discursive interaction do students pause to consider whether this device is their "best" design beyond reference to its design elements or data results (i.e., they do not consider, for example, how the specifications may affect the patient).

Next, Glenn makes an effort to share the details of another device for consideration by the team (Figure 5.19b, below). His teammates (Rick, Carole, Daryl and Maggie) quickly convey the issues they have with this possibility (i.e., their *opinions*). In doing so they only note the limitations of the specifications, and do not provide a rationale (i.e., APT-C: *Share Reasoning*) or explanation (i.e., APT-C: *Explain*) as to why, as did the groups with higher APT use in discourse (c.f., the conversational exchange presented in Figure 5.18a, above, which results in the group integrating the client, for example, into their design thinking through doing so).

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Glenn	DECLARE: *Present*	I did have one device with a reliability of 6, a marketability of 700,000, a flux of 11, a BCR of 10, and a cost of 140<->The extra cost and the lower flux and reliability probably do not full compensate for the extremely low BCR.	Design (Knowledge) Tech. Knowledge (1)
Rick	DECLARE: *POV*	I think the reliability is too low on that one	Tech. Knowledge (1)
Carol	APT-C: *Agree/Disagree*	Same	
Daryl	DECLARE: *POV*	I think the flux is too low	Tech. Knowledge (1)
Maggie	APT-C: *Agree/Disagree*	Yeah, the flux may also be too low.	Tech. Knowledge (1)

*Figure 5.19b***.** Chat log excerpt from a lower APT use group in Conversation 4.

Rick then asks the group for another device that may be better, indicating that he is not ready to settle on what they have (Figure 5.19c, below). After Daryl indicates he doesn't have one, Carol shares information about another device from her prior design team, detailing the data specifications of the design. The rest of the team quickly discounts this device, but there is no indication in their discourse as to why or its implications (i.e., *why* were BCR and cost too high; how affect the client). Although there may be implicit understandings among the team about this (i.e., possessed by individuals), it is not explicitly explored in their discourse, and thus not integrated into, or represented in, the group's design thinking.

Student	**Conversational Category: *Move***	**Student Utterance**	**Epistemic Code(s)**
Rick	ELICIT: *Clarify*	does anyone else have a device better than this one?	Design (Knowledge)
Daryl	DECLARE: *Inform*	not me	
Carol	DECLARE: *Inform*	From my old team, we had some pretty high numbers<->give me two secs to put them down<->The top two<->1.) PLNRT, vapor, hydrophylic sufactant and 10% nano: reliability of 12, marketability of 800000, flux 17, bcr 76.67 cost 150<->2. Same composition except for 6% nanotubes: Reliability 11, Marketability 700000, flux 17, bcr 76.67, cost 140	Data (Knowledge) Identity Engineer Tech. Knowledge (1,4,5)
Glenn	DECLARE: *POV*	It think the BCR is unfortunately high.	
Daryl	APT-C: *Agree/Disagree*	yes i agree	
Rick	DECLARE: *POV*	i just think the BCR is too high for those two	
Carol	APT-C: *Agree/Disagree*	thats what i thought too	
Maggie	DECLARE: *POV*	The flux rate is great, but the cost is high.	Tech. Knowledge (1)
Carol	DECLARE: *Inform*	every device we made w/plnrt hadf that same bcr	Design (Knowledge & Skill)
Maggie	DECLARE: *Inform*	along with the BCR	

*Figure 5.19c***.** Chat log excerpt from a lower APT use group in Conversation 4.

Finally, the team appears to lose momentum, or possibly run out of time, and quickly moves to consensus on the specifications for the final device they will submit in the internship (Figure 5.19d, below). Their discussion closes with Rick providing details that provide an integration of data analysis and engineering design elements into the team's discussion.

Student	Conversational Category: *Move*	Student Utterance	Epistemic Code(s)
Daryl	APT-C: *Agree/Disagree*	so do we all agree that Pes-Pvp, Biological, Phase, 10% is the best device?	Engineering Design Tech. Knowledge (2,4)
Carol	APT-C: *Agree/Disagree*	sure	
Glenn	APT-C: *Agree/Disagree*	Yes.	
Maggie	APT-C: *Agree/Disagree*	Yes.	
Rick	APT-C: *Agree/Disagree*	i think so	
Glenn	ELICIT: *Clarify*	Who proposed that device? As in, which team member is an expert in Pes PVP?	Design (Knowledge)
Rick	DECLARE: *Inform*	I did <-> my previous team used all 20% CNT for our prototypes so for this one i decided it would be a good idea to try it with lower and the results improved. <-> The CNT% only changed the marketability for the original device i changed it from <-> So that means the CNT% was affecting the marketability the most for our devices	Data Analysis Engineering Design Collaboration Identity Engineer Tech. Knowledge (1,5)

Figure 5.19d. Chat log excerpt from a lower APT use group in Conversation 4.

Summary of representative samples of groups with differing levels of APT use in Conversation 4

As presented in the representative samples above, the use of more APT in group discourse resulted in the integration of the needs of *the client* into student's design thinking. In particular, the specific use of the substantive APT-Conversational moves *Share Reasoning* and *Explain* in student discourse yielded such integration. As was evident in the samples of discourse from Conversation 3, the use of higher degrees of APT in group discourse, in general, led to more specific discussion of implications for their designs and/or explained the thought or decision-making process of their groups.

In contrast, the discourse of the lower APT use group reflects a pattern of interaction that was overly focused on the technical specifications of their device and less substantive regarding the implications of their design. In particular, while their device may have "tested" well, the discourse of the lower APT use group did not reflect evidence that they were integrating the client's needs into their design thinking. As was also found in the analysis of Conversation 3, this highlights how lower APT use groups did not integrate the client into their design thinking, as it did in high APT use groups, who evidenced the use of APT beyond the signaling of agreement or disagreement (i.e., *Explain, Share Reasoning, Restate, Challenge*). Said another way, higher APT use groups were better able to focus on a critical connection in their conversation, namely to *the client*, which suggests their more frequent use substantive APT moves in discourse facilitated a more nuanced engineering epistemic frame, compared to groups that used lower degrees of APT. This difference is particularly salient for groups' design process in that groups that engaged in more collaborative discourse in this final conversation were better able to keep concerns related to the product's end user (i.e., the client) in mind as they prepared to submit their final device for testing.

5.6.4 Group level characteristics associated with APT use in Conversation 4

As before, ENA was also conducted to test whether group-level characteristics were associated with the types and frequencies of epistemic connections groups made in relation to level of APT use in discourse. T-tests indicated that there are strong, practical associations between APT use and group's gender balance and groups' degree of contribution equality in discourse. As will be described below, greater gender balance and contribution equality yielded connections more akin to those found for higher APT use groups in general, particularly among lower APT use groups. No associative differences were found regarding the use of APT and the group-level characteristics of level of experience (i.e. Novice or Advanced), nor groups' average level of confidence, commitment or self-efficacy.

Gender balance

In what follows I present evidence which suggests that there were strong practical effects (based on Cohen's *d*) for how gender balanced groups (even if nominally) integrated the epistemic elements of data analysis and the consultant, or the client, into their design thinking regardless of level of APT use, more so than groups comprised of only male students. First, Figure 5.20 (below, left panel) displays a plot of the means of the network connections for groups with *higher* APT use Conversation 4, controlling for gender balance.

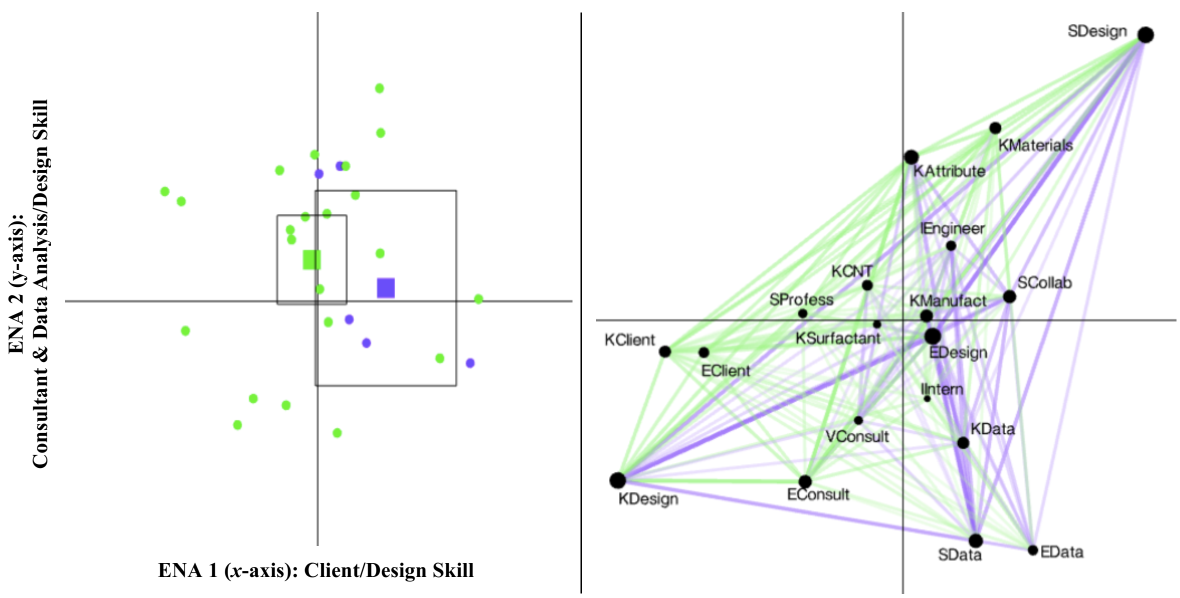

Figure 5.20. LEFT PANEL: Plot of mean of network connections for gender-balanced (green, n=22) and all-male (purple, n=6) groups with higher APT use in Conversation 4. RIGHT PANEL: Comparative model of discourse for gender-balanced and all-male groups with higher APT use in Conversation 4.

Among groups with higher APT use, those that were not all-male had lower average scores on ENA dimension 1 (i.e., Client/Design Skill) ((t)-2.274, p=0.041, d=1.02). This indicates that such groups more frequently integrated their client's interests into their design thinking than did all-male groups. Also displayed (right panel, above) is a comparative equiload model highlighting the relative strength of how more gender-balanced groups with higher APT use (in purple), compared to all-male groups, made more and stronger connections between the client and other aspects of engineering practice in their discourse (including the consultant, engineering design knowledge and skill, and data (knowledge, skill, and epistemology)). It is important to note that this finding reflects the epistemic discourse of higher APT use groups, in general, in this conversation, as presented above.

Second, among *lower* APT use groups (see Figure 5.21, below, left panel), those that were not all-male (in green) had lower average scores on ENA dimension 2 (i.e., Consultant & Data Analysis/Design Skill) ((t)-2.305, p=0.046, d=1.01), compared to all-male groups (in purple). This indicates that they more frequently made connections between the consultant, data analysis, and other aspects of engineering practice, in their discourse[37]. As before, Figure 5.21 (below, right panel) displays a comparative equiload model that reflects how groups with gender-balance more frequently integrated the needs/interests of the consultant and data analysis as justification in their design thinking.

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[37] ENA results also indicated that this finding persisted when considering both conversations in this design cycle level (i.e., over time) ((t)-2.558, p=0.025, d=1.22).

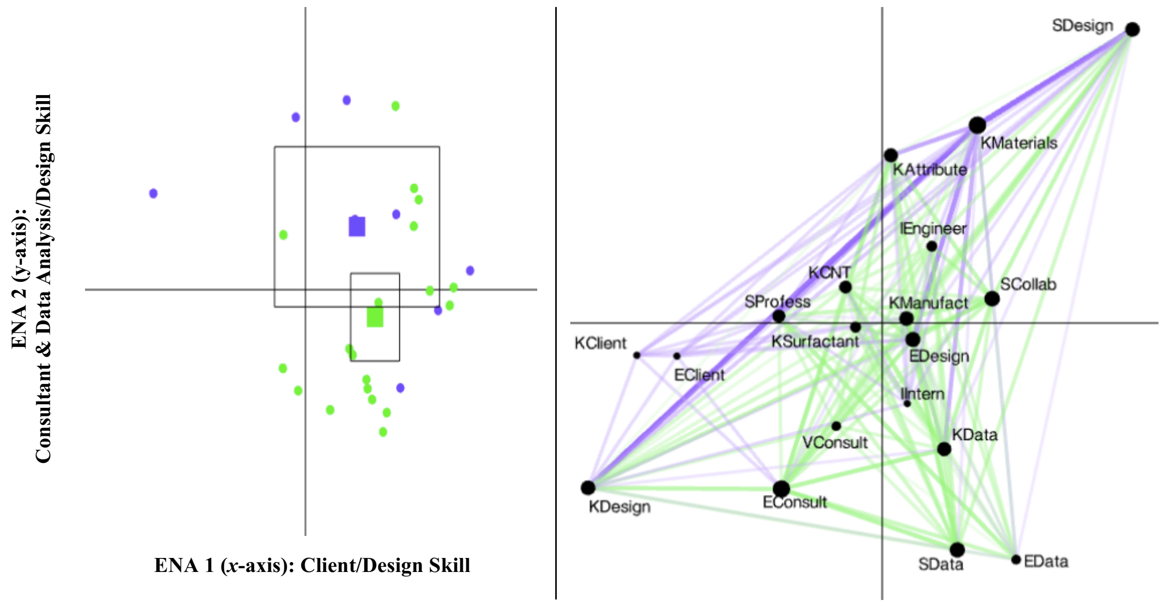


Figure 5.21. LEFT PANEL: Plot of mean of network connections for gender-balanced (green, n=19) and all-male (purple, n=8) groups with lower APT use in Conversation 4. RIGHT PANEL: Comparative model of discourse for gender-balanced and all-male groups with lower APT use in Conversation 4.

Taken together, these findings imply that all-male groups, on average, tended to focus primarily on the skill of engineering design, at the expense of more nuanced conversation that integrated other critical, domain-based connections, as they finalized their devices for submission at the end of the simulation. Conversely, this also implies that being in a group with female students, even if nominally, may support: (1) the development of more robust epistemic frames of engineering practice; and (2) the submission of a final device that better reflects the human-centered constraints students are expected to consider, and that is informed by the data about their previously prototyped devices.

Contribution Equality

ENA results also indicated that among *lower* APT use groups, those with higher degrees of contribution equality (i.e., groups with more balanced participation among team members) more frequently made connections between aspects of the consultant, data analysis, and other aspects of engineering design, compared to groups with less contribution equality ((t)-2.179, p=0.039, d=0.84) (Figure 5.22, below, left panel). The effect size value (d=0.84) suggests that increased contribution equality in this conversation is strongly associated with the integration of such epistemic elements into students' design thinking in groups with lower APT use in Conversation 4.

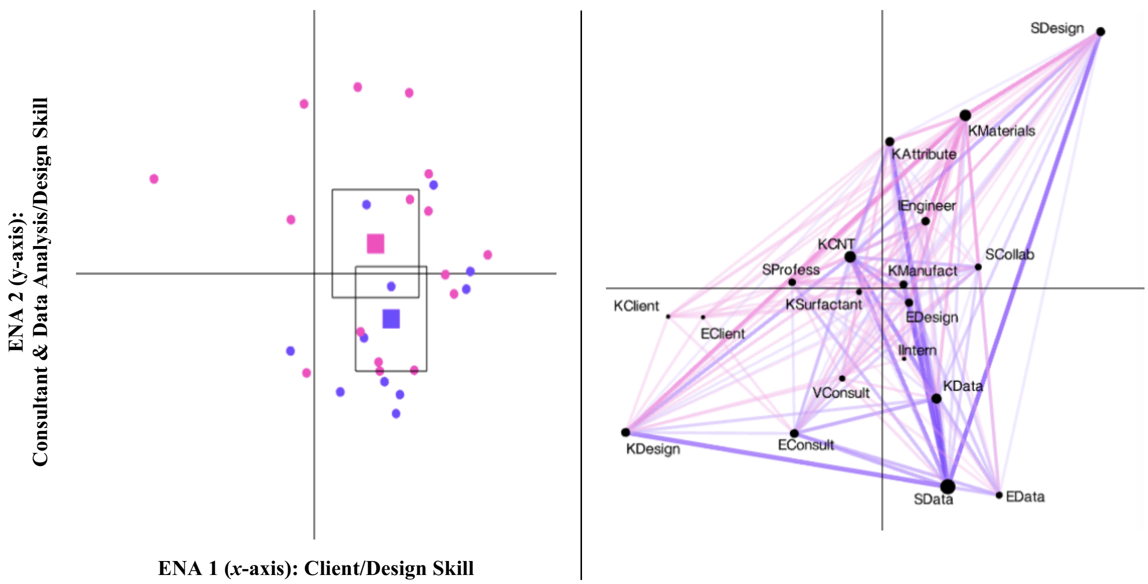


Figure 5.22. LEFT PANEL: Plot of mean of network connections for lower APT use groups with higher (purple, n=11) and lower (pink, n=16) contribution equality in Conversation 4. RIGHT PANEL: Comparative model of discourse for lower APT use groups with higher and lower contribution equality in Conversation 4.

Additionally, as displayed in the comparative equiload model in Figure 5.22 (above, right panel), this finding implies that groups with greater contribution equality more frequently connected elements of data analysis, and to some extent, their consultant's interests, to other epistemic elements in their discourse than did groups with less balanced participation among teammates. This suggests that more balanced participation among teammates in the final design meeting may support groups in making critical connections to these aspects of engineering design practice, which in turn, could yield a higher quality final device design. This finding is also important in that it suggests that contribution equality, at least in Conversation 4, mediated the effects of less APT in student discourse.

5.6.5 Summary of Conversation 4 findings

In summary, my analysis of the ENA results and qualitative review of utterance data presented above found that groups that used more collaborative conversational moves (as evidenced by APT) in Conversation 4, compared to those that used fewer, more frequently integrated *the client* (i.e., the patient's wellbeing, health, comfort and/or safety) into their design thinking. This suggests that there was a relationship between a group's greater overall use of substantive APT moves (i.e., those that do more than signal agreement/disagreement), as a proportion of all moves, in Conversation 4 and students' contributions in these groups that also made more frequent and stronger connections to this important aspect of domain-specific discourse.

My analysis also found that gender-balance in group composition and higher contribution equality among teammates in lower APT use groups in Conversation 4 were, on average, better able to integrate a broader array of epistemic elements into their design thinking (i.e., the consultant, the client, data analysis). This also implies that such groups also developed richer and more nuanced "epistemic frames" of engineering practice.

Lastly, my analysis found that the effects of APT were different in Conversations 3 and 4, particularly with regard to better integration of *the consultant* or *the client,* respectively, into students' design thinking. This difference suggests that the effects of APT may be context specific in terms of the focus of the task in each conversation.

5.7 Discussion

In this part of my study I used chat-log (i.e., utterance) data from four, 30-40 minute long design team meeting conversations held by 110 unique student groups in the virtual internship, *Nephrotex*, to empirically test my hypotheses for research question two. I hypothesized that groups with higher proportions of *Academically Productive Talk* (APT) in their discourse would make connections in their discourse: (1) to more epistemic frame elements (i.e., larger networks, with a greater *variety* of connections); and (2) among more epistemic frame elements (i.e., denser networks, with a greater *number of connections*). To test these hypotheses, I conducted ENA to examine the groups' discourse as they collaborated to solve a complex engineering design problem.

I expected to find evidence of collaborative conversational contributions (i.e. APT moves) in my analysis of student discourse because *Nephrotex* is an "intentional" CSCL environment designed, in part, to mediate, support and facilitate group interaction wherein students learn and build knowledge collaboratively (Stahl, 2006) in order to design a medical device that met an array of pre-determined constraints. APT moves characterized 41% (n=6109) of all student design team meeting utterances in the conversations considered in my analysis (N=15068). The fact that there was such a prominent and endogenous use of APT in the simulation adds support to two assertions. The first is that the design of the simulation is well-structured because it fostered and engendered non-scripted, collaborative interaction through discourse (Blumenfeld et al., 1996; Rahman et al., 2010; Mercer, 1996; Soller et al., 1998). The second, in line with prior research on the effects of APT, is that students, in general, engaged in reasoned participation and effective discourse in their design team meetings (Michaels et al., 2008; Adamson et al. 2013; Resnick et al. 1993, 2013).

My analysis found that there were differences in groups' emerging "epistemic frames" as engineers associated with the use of APT, as a proportion of all types of conversational contributions, in design team meeting discourse. However, these differences were only statistically significant in the second half of the internship experience (i.e., Design Cycle 2). In the two conversations in this design cycle, findings indicated that higher APT use groups made a number of critical, domain-specific (i.e., epistemic) connections in their discourse as they collaborated on the completion of their task in a way that lower APT use groups did not.

Specifically, these critical connections resulted in better integration of *the consultant* (i.e., his/her needs, interest, and expectations) and of *data analysis* (i.e., knowledge, skill, and epistemology) into students' design thinking in Conversation 3, and a better integration of *the client* (i.e., the patient's wellbeing, health, comfort and/or safety) in Conversation 4. As will be discussed below, the fact that the findings about the effects of APT in student discourse were different in each conversation suggests that the relationship between the use of APT and the types of epistemic connections made in discourse may be context (i.e., conversation) specific, and related to the different foci in the conversations (i.e., organizing as a new group to identify viable models for testing in Conversation 3; converging on final device proposals in Conversation 4).

These findings are important because they suggest that APT served as an important mechanism in student discourse, namely, that its use in group discourse facilitated the construction of discipline-specific understandings and the integration of content knowledge into student design thinking. That is, by coupling ENA with a frequency-based measure of APT in my analysis of design team meeting discourse in *Nephrotex*, I found evidence that groups that used *more* APT in their discourse in Design Cycle 2 conversations achieved better integration. However, my analysis of the qualitative data (i.e., chat-logs) also suggests that using the frequency (i.e., greater or lesser) of overall APT use, as was used in this study, use may be too gross of a measure. As such, future research should consider whether it is actually increases in the *quality* of APT use and/or increases in the use of specific moves, or patterns of moves, in discourse that lead to better integration.

The evidence presented in my analysis is generally consistent with findings reported in the literature about skills associated with collaborative problem solving (CPS), the relationship between communication activity and collaborative outcomes, and the effects of APT in CSCL environments. These findings also shed light on why APT was an effective mechanism for the integration discipline-specific knowledge and understanding. First, the effects of greater APT use in design team meeting discourse found in my analysis can be broadly interpreted in light of the types of cognitive and social skills detailed in the literature that are commonly associated with effective CPS, which is characterized as interactive, interdependent, and dynamic (c.f., Griffin at al., 2011; O'Neill et al., 2003; OECD, 2013). For instance, my analysis suggests that increased use of APT in the second Design Cycle of the *Nephrotex* internship was an indication that students were demonstrating an ability to enact important skills in the service of work on their design problem, such as knowledge building (i.e., contributing information and skill-based knowledge), social regulation (i.e., negotiating misunderstandings and conflicts of ideas), perspective taking (i.e., considering the ideas put forth by others), and effective communication (i.e., clarifying and acknowledging other's ideas) in a way that affected the overall development of their epistemic frame as engineers. The effects of APT found in my analysis also point to how students were engaged in decision-making through integrating information, using judgment, identifying alternatives, and evaluating consequences, which are all facets of what APT "looks like" when it is used in student discourse. Future design-based research could examine these effects in more detail to determine whether APT could be used to formatively assess student's ability to demonstrate such skills and/or as a way to measure the process and quality of collaboration in problem solving in a simulation-based environment, such as *Nephrotex*.

Second, prior research has established that communication activity (i.e., discourse) plays a central role in how people learn through collaboration in CSCL environments (Steinkuler, 2006, Stahl, 2006). In accord with the literature, my study used the APT framework to identify collaborative conversational moves in order to better understand the outcomes of collaborative discourse in the *Nephrotex* simulation (Stahl and Hesse, 2006; Dillenbourg, 1999; Wooley et al., 2010). Broadly speaking, the findings reported in my analysis are consistent with research that suggests that the outcomes of collaboration, which in this study were codified in groups' epistemic frames as engineers, are affected by the nature and quality of social interaction (Kreijns et al., 2003). For instance, the fact that increased use of APT in groups was found to affect the development of their epistemic frame of engineering practice reflects how the quality of group interaction and participation patterns were related to the outcomes of collaboration (Webb, 1991; Kittleson and Southerland, 2004; Soller et al., 1998; Blumenfeld et al., 1996; Rahman et al., 2010). Additionally, these findings can also be interpreted as an indication that greater use of APT in discourse supported groups' development of shared knowledge and understanding via "active learning" (i.e., justifications, elaborations, explanations), the characteristics of which are found in the conversational moves codified in the APT framework (Roschelle, 1992; Soller et al., 1998). However, because much of the aforementioned research focused on examining the relationship between collaboration, social communication/interaction, and *individual* outcomes, my findings also expand this literature by suggesting that a particular type of social interaction, APT, could be used in future research to study group-level outcomes.

Lastly, the results of my analysis are consistent with prior research on the effects of APT in CSCL environments that has established the use of APT effectively supports reasoned participation and fosters effective discourse. My findings can be broadly interpreted to indicate that greater use of APT, specifically in Design Cycle 2 of the *Nephrotex* simulation, affected the types of connections students made in their discourse because it supported deeper levels of engagement among students in their content-specific discussions, yielded more elaborate and discipline-specific reasoning, and improved their knowledge structures as they engaged in their collaborative design challenge (Michaels et al., 2008; Adamson et al. 2013; Resnick et al. 1993, 2013). In turn, the differences in group's epistemic networks can be interpreted as reflecting particular types of meaning making and characteristically different knowledge structures stimulated by increased use of APT in discourse, because it led to "pockets of intensive discussion" that occurred concurrent with, and around, its use in discourse (Adamson et al., 2014; Dyke et al., 2013). Said another way, my analysis suggests that when groups engaged in talk that was more "academically productive" they were better able to integrate domain-specific knowledge and understandings into their design thinking because they were engaging in more critical and reasoned discussion.

Next, I present a more detailed discussion of the findings from my analysis that found empirical evidence of a relationship between *how* students talk (i.e., the syntactic function of contributions) and *what* they talk about (i.e., the semantic nature of those contributions) with regard to APT. In particular, my analysis found that "when" and "how" APT mattered was different in terms of the development of a group's engineering epistemic frame.

"When" APT mattered in the Nephrotex simulation

My analysis found that greater use of APT in design meeting discourse appeared to "matter" in the second half of the internship experience (i.e., Design Cycle 2) when students were converging on, and justifying, their final device designs for submission. In Design Cycle 1, APT use in groups was not found to influence the types of epistemic connections they made in their design meeting discourse. That is, the use of APT in group discourse affected a difference in groups' development of an engineering epistemic frame only in design meetings in the second design cycle.

One plausible explanation for the difference in findings on "when" APT use appeared to matter may be explained, in part, by the nature of the work groups engaged in (i.e., task structure) in each design cycle and that reflect the design of the simulation experience (Blumenfeld et al., 1996; Rahman et al., 2010). For instance, in the first Design Cycle, much of each group's activity was focused on the sharing and discussion of the research conducted, and results obtained from device prototype testing, by *individual* team members. In this light, and although groups made team-based decisions at the end of Conversation 2, the central work of the group could be said to be more reflective of how cooperative work is characterized in the literature (e.g., individual responsibility for a portion of the task; separate "solutions" at play; etc.) (Weinberger, 2003; Hamalainen, 2006; Dillenbourg, 1999; Roschelle & Teasley, 1995; Soller et al., 1998). This is not to say that groups were not expected to collaborate or that the decisions they made were not expected to be driven by their group's conversation, but that the focus of groups' work was on incorporating what individuals brought to the conversation to develop group-level knowledge and understanding of the design problem.

In contrast, the central work of groups in Design Cycle 2 could be interpreted to reflect activity that demanded more collaboration to be successful (e.g., mutual engagement; synchronized effort; developing a shared understanding and solution to a problem or task) as teams worked to coalesce around a body of findings they obtained in their Design Cycle 1 groups so as to come to consensus around a team decision for submission of their final device. Viewed in this light, this suggests that the design team meetings in Design Cycle 2 were less exploratory and more about the refinement of devices in line with design constraints and the analysis of data from the performance of previously prototyped devices. As such, it makes sense that more collaborative discourse would be salient in terms of a group's ability to better integrate critical domain-specific connections in a way that enhanced the design of their final device in the internship. Alternatively, it is also possible that the differences in these findings point to how some groups may have responded to increased stakes in the second half of the simulation by engaging in more collaborative discourse as they worked to make meaning of a greater amount of information at their disposal, and to be more precise in their conversations as they prepared their final devices for submission. Yet another explanation is that the differences are a function of student experience over the course of internship. This would suggest that some students may have gotten better over time at working in the simulated context as a member of a virtual design team, which in turn affected how their groups communicated.

In the next section, I discuss these findings in more detail in terms of "how" APT mattered, specifically in the context of conversations in Design Cycle 2. As such, these findings should be interpreted with caution because APT was found to affect the epistemic discourse of groups only in this design cycle.

"How" APT mattered in the Nephrotex simulation

My analysis found that the effects of more APT use in group discourse mattered in different ways *within* Design Cycle 2 (i.e., in Conversations 3 and 4) in that greater APT use affected the integration of different types of epistemic elements into students' design thinking. As above, these differences can be explained by the different foci (i.e., task structure) of each conversation in the arc of the simulation (Blumenfeld et al., 1996; Rahman et al., 2010). First, I present a discussion of the unique findings for each conversation, followed by a discussion of why the findings varied across conversations.

Conversation 3

My analysis found that APT moves accounted for 22% of all types of syntactic contributions in Conversation 3 - the only design team meeting when they were not the most prominent type of contribution. This was an unexpected finding, though can be explained by the nature of the task in this phase of the design process. In this conversation, groups needed to synthesize the data, findings, and consultant constraints brought to their new group in order to account for the range of materials and attributes they worked with in their first team in Design Cycle 1 (i.e., Design Cycle 1 groups worked with 1 of 5 possible materials, and incorporated different attributes based on consultants' interests). It therefore makes sense that Declaration moves (i.e., *Present, Point of View, Inform, Activity*) accounted for such a high proportion of conversational contributions in this conversation (35%), relative to other types, as students had a great deal of information to convey to their new team.

Findings did indicate, however, that high APT use (> 29%) in this design team meeting supported those group's development of a more robust "epistemic frame" as engineers, compared to other groups that used non-high degrees of APT (0% - 29%). More specifically, groups that engaged in more talk that was "academically productive" supported groups' integration of what prior test results (i.e., data) about the performance of different materials and attributes suggested for the new group's designs, as well as, how all of the consultant's needs/interests should be considered to justify their forthcoming design decision.

This suggests that, in Conversation 3, greater APT use in groups may have served a unique function in this conversation that brought more nuanced, content-specific considerations into their design thinking as they worked collaboratively to synthesize the knowledge and understanding each group member acquired in their first group, to generate new and improved devices to meet a broader range of constraints in their new group. This also suggests that when group members did not, for example, encourage their peers to explain their reasoning, or provide any of their own, their group was more likely to take the points of view, information and proposals put forth by their teammates at face value, resulting in less integration of the critical, domain-based connections related to data analysis and the consultant into their discourse. That is, more APT in Conversation 3 led to more elaborate and reasoned discipline-specific discussion about the implications for, and efficacy of, design choices.

My analysis also found that the effects of APT were associated with the level of experience (i.e., Novice or Advanced) of the players in this conversation. In particular, regardless of level of APT use in groups, Advanced students evidenced less robust epistemic networks, in relation to APT use, than did Novice students in that they made fewer connections to epistemic elements related to data analysis, the consultant, and/or the client. One explanation for this finding is that Advanced groups just made fewer references, overall, to these epistemic elements in this conversation. This could mean that they accounted for them in other conversations, in off-line communication (i.e., chats send outside of the "room" structure of the simulation), and/or included them in shared notebook entries, which were not analyzed in this study. Another explanation for these differences is that APT-style contributions may not have been particularly helpful for

Advanced groups with regard to whether they made connections between and among these epistemic elements in this conversation. This makes sense in light of prior findings reported by Dyke et al. (2013) and Adamson et al. (2014) which suggest that for more advanced learners, or learners working with material that is less challenging and/or or familiar to them, the effects of APT in their discourse are diminished. Said another way, it is possible that Advanced students, compared to Novices, may have approached this conversation in a manner that suggests that they were already good at synthesizing information in ways that didn't require more collaborative interaction to surface and/or integrate them into their design thinking. As such, this implies that in the context of this one conversation, APT may have been particularly helpful for Novice students to integrate these epistemic elements into their design thinking, whereas it was not as necessary for Advanced students to do so.

Conversation 4

My analysis found that the median use of APT moves accounted for almost half (47%) of all types of contributions in Conversation 4. Findings indicated that higher APT use (range: 47% - 75%) in this design team meeting, as a proportion of all types of utterances, supported group's development of a more nuanced "epistemic frame" as engineers, compared to groups that used lower degrees of APT (range: 11%-46%), in one particular way. Specifically, groups engaging in more talk that was "academically productive" supported the integration of considerations about the health and well-being of *the client* into their design thinking. The implication of higher APT-use groups more frequently making such connections is that they were better able to focus on critical and domain-based content connections to the client at a key phase of their design process, namely, when they were finalizing their "best" design for submission.

One explanation for this is that the richer, more substantive interactions that resulted from increased APT use in groups may have pushed them beyond focusing on the technical specifications of their devices and how well they "tested," and toward more nuanced considerations in their design thinking. That is, students providing justifications for their positions and/or explaining the efficacy of ideas under consideration, for instance, may have helped their groups to more specifically addresses the implications for their design with regard to the client. Relatedly, this also suggests that groups that relied more on declarative (i.e., student's sharing opinions, presenting of information, or informing others about the details of their device specifications) or eliciting (i.e., seeking information from teammates) contributions were less effective at incorporating the client into their design thinking at the end of the simulation. This difference is particularly noteworthy for groups' design process in that it implies that groups that engaged in more collaborative discourse - in this final conversation – did a better job of keeping concerns related to the product's end user (i.e., the client) in mind as they prepared to submit their final device for testing.

My analysis also found that two group-level characteristics, gender-balance and contribution equality, were associated with the effects of APT use in groups in Conversation 4. This can be interpreted to mean that in this conversation, the quality of interaction of lower APT use groups, in particular, was improved as a function of gender balance (heterogeneous group composition) and contribution equality in a way that facilitated more robust epistemic connections in their discourse, overall (Richmond and

Striley, 1996; Bear and Wooley, 2011; Van den Bossche et al., 2006; Webb et al., 1998; Wooley et al., 2010; Storch 2002; 2009; Weinberger and Fischer; 2006). It was, however, surprising that these effects were only found in this one conversation. Therefore, these findings should be interpreted with a degree of caution as this study did not examine whether these group-level characteristics were associated with different types of epistemic connections in discourse in general, nor with APT use in Design Cycle 1 conversations. However, these findings also suggest a number of avenues for future investigation. First, further study could investigate whether gender-balance and/or contribution equality are related to the nature and quality of epistemic discourse in general. Second, future research could consider whether particular activities in the simulation may be better suited to conversations that are more or less facilitated as a means of obtaining the objectives of different tasks at different points in the internship (i.e., Do specific conversations benefit from more or less contribution equality?). Finally, an intervention-based study could investigate the effects of less random group assignment in the simulation by intentionally distributing female students across groups.

It is also important to note that there was one group-level association that I was surprised did not play out in my analysis, given that it is reported in a number of prior studies that examined factors that influence group conversational interaction in game-based environments. Specifically, research has shown that students' personal perspectives (i.e., prior attitudes, perceptions, dispositions, etc.) influence their social, collaborative interaction in simulated environments (c.f., Bluemink et al., 2010; Kritzenberger, 2012; Giannakos, 2013; OECD, 2013). In my analysis, however, student perspectives (i.e., sense of self efficacy, commitment, confidence) were not found to be associated with the use of APT in *Nephrotex* design team meeting discourse. One explanation for this is that such perspectives may not influence the use of APT in discourse. It is also possible that student's perspectives may have played a role on the outcomes of their group's collaborative activity in ways unrelated to their group's use of APT, and which were not considered in the design of this study. A final explanation is that the measures I used to characterize student perceptions (i.e., group average of individual student perceptions) were weak constructs and insufficient for detecting any associations. Future studies, using different constructs all together, or ones designed to account for the relationship between individual student perspectives and the use of APT, could explore this topic in greater detail.

APT and the integration of different human-centered design constraints

What is consistent in the findings, discussed above, for Conversations 3 and 4 is that increased use of APT in group discourse was found to be related to more robust epistemic networks with regard to integrating human-centered design constraints related to the client and the consultant. This is an important finding because these epistemic elements occurred relatively infrequently in student discourse, being evident in only 0.9% and 1.8% of utterances, respectively, in Design Cycle 2. What this points to is that APT appears to have been an effective strategy that supported groups' incorporation of these rare epistemic elements into their design thinking, in the second phase of the design process. The difference in *which* constraint was better integrated into group's design thinking in each conversation, however, suggests that the effects of APT varied as a function of the focal work in each design meeting.

The shift in effect of APT on the incorporation of *the consultant* in Conversation 3 to *the client* in Conversation 4 can be interpreted in the following way. In Conversation 3, groups were tasked with building their knowledge and integrating the findings collected by students in their Design Cycle 1 groups about how different design materials and device attributes tested in relation to consultants' interests in order to prototype new and more complex devices for testing. It therefore makes sense that more collaborative interaction would yield a better integration of the consultant into their design thinking, as higher APT use groups spent more time engaged in critical and effective discourse.

In contrast, the focal work of the group was different in Conversation 4. In this activity, groups were expected to consider the results of how their newly tested devices performed in order to come to consensus on a single, final device that would best satisfy the design constraints with regard to the interests of the consultants *and* the needs of the client. In this conversation, greater or lesser use of APT was not related to how well groups integrated the consultant and data analysis in their design thinking - groups had already synthesized their knowledge of prior performance data and understandings of various consultants' interests *prior to* this conversation. The shift in how APT affected epistemic discourse to focus on the client in this conversation therefore makes sense because it suggests that more elaborate, discipline-specific reasoning in Conversation 4 supported groups' surfacing and accounting for the health and well being of the client in the specifications for their final device submission in the simulation.

Summary

In this study, I coupled two approaches to examine student discourse. The first approach was ENA, which measures of the amount and the quality (i.e., kind) of epistemic integration (i.e., the semantic nature of student utterances; "what" students talk about). The second approach was APT, which characterizes collaborative conversational contributions (i.e., the syntactic nature of student utterances; "how" students talk). As discussed above, my analysis about the relationship between how students talk (i.e., syntactic contributions) and what they talk about (i.e., semantic contributions) is generally consistent with reports in the literature that suggests that APT supports: (1) increased depth of student engagement and interactivity; (2) the development of richer knowledge structures; and (3) improvements in the overall collaborative nature of student discourse in CSCL environments. However, my findings also expand upon this literature in a number of ways, and will be discussed in what follows.

While prior studies report that APT is an effective support for collaborative learning in general (Adamson et al., 2014; Hamalainen, 2006; Weinburger et al., 2005), this study presents evidence that APT was an effective support for a particular *aspect* of collaborative learning, namely the degree to which it facilitated the development of a more robust epistemic frame of engineering practice (i.e., better integration of complex, discipline-specific knowledge and understanding, as measured by ENA, in their discourse). As such, my findings also suggest that because increased use of APT in discourse was found to be an effective measure of more integration of particular epistemic elements in discourse, APT is a syntactic mechanism through which ENA can also be interpreted (i.e., why the observed amount of content integration in discourse occurs).

This study also extends and contributes to knowledge in the field regarding the effects of APT in a game-based, simulated learning environment, a CSCL context not yet examined in the literature. Therefore, my findings extend prior research about the effects of APT by presenting evidence that there was a relationship between the use of APT and the learning of, and knowledge structures developed by, groups through discourse in the situated, social activity of the *Nephrotex* simulation. From a socio-cognitive perspective, this is an important finding because it suggests that the group was an appropriate unit of analysis in the study of a particular type of social interaction on the outcome of collaboration (Stahl, 2006; Dillenbourg et al., 1996; Dillenbourg, 1999).

Similarly, my analysis also contributes to the existing literature on the effects of APT on student outcomes in that the only metrics used in prior studies were gains in learning based on pre/post test scores (Chaudhuir et al., 2009; Ai et al., 2010; Kumar et al., 2010). As such, my findings expand upon this literature to suggest that non-traditional measures of learning can also be used to evaluate the effects of APT in student discourse, such as the development of an epistemic frame. Lastly, the use of the APT framework in practice and research is most commonly done in a scripted context (i.e., students and/or facilitators are tasked with using the framework), and research on APT has primarily focused on the use of *specific* moves in the APT framework in controlled-intervention studies. Therefore, this analysis contributes to the literature about APT because it suggests that the general use of APT in discourse (i.e., how much of discourse was characterized as APT in nature), in a non-scripted/un-prompted context, yielded particular types of meaning making and characteristically different knowledge structures in student discourse.

My analysis is also consistent with prior research conducted with data specifically from the *Nephrotex* simulation that reports that chat-log data of student discourse was effective at assessing the attainment of educational outcomes in relation to ABET (2011) criteria (Chesler et al., 2013), from which the epistemic coding used in this analysis was partly derived. My analysis expands upon these findings because the use of APT, in particular, was found to yield a better integration of a number of these outcomes in student's discourse. This suggests that, as a particular type of discursive interaction, APT could be used as a way to codify student's ability to demonstrate key student outcome criteria outlined by ABET (2011), such as the analysis and interpretation of data (i.e., data analysis), accounting for needs and constraints imposed on their design process (i.e., consultant), and engaging in a design process that considers constraints related to the health and safety of the end user of the product (i.e., the client).

Lastly, my findings also contribute to the expanding literature about the efficacy of epistemic games, in general, which has identified relationships between epistemic discourse and a number of different outcomes such as civic engagement, increased content learning, social identity formation, and changes in views of careers in engineering (Nash et al., 2012; Chesler et al., 2013; Arastoopour et al., 2013; Arastoopour et al., 2012). Therefore, this analysis extends these findings to suggest that the relationship between epistemic discourse (i.e., semantic contributions) and the aforementioned outcomes may also be related to *how* students talk (i.e., syntactic contributions) in the simulation. This is an area that future design-based research could explore in greater detail by controlling for particular types and/or frequencies of interaction as they relate to APT, or the other types of talk identified in this analysis (i.e. Declarations, Proposals, Eliciting, Administrative).

5.8 Implications

Beyond those already discussed, the findings from my analysis reported above suggest a number of additional implications for practice with regard to APT and epistemic games specifically, as well as areas for future research to explore. Firstly, although the *Nephrotex* environment is mildly facilitated by mentors, there are no pre-established guidelines regarding *how* students should organize themselves for engaging in conversation (i.e., no role establishment, etc.) or interact in their groups. Therefore, one implication for practice implied by my findings is that students could learn how to strategically use APT in their discourse as a way to interact with content and materials in more complex ways. This learning could occur prior to, or be embedded in, the simulation experience. Future research could test the efficacy of such an approach to determine if the intentional incorporation of the APT framework into the architecture of the simulation experience yields improvements in engagement and collaborative interaction, and, ultimately, outcomes in a way that helps students to become better designers and engineers.

Relatedly, a second implication has to do with the ongoing development of mentor scripts, whether automated or in real-time, that could prompt students to use APT-style moves in discourse in the simulation. Simulation designers could consider the findings from this analysis as they further develop and refine the mentor scripts used in the game environment to include the explicit introduction of APT-style facilitation moves and/or ways of encouraging students to use such moves. Future research, using a controlled intervention study, could test whether the *intentional* use of APT scripts in the simulation would yield more robust, or different types of, epistemic connections in student discourse.

Third, although my findings indicated that APT affected epistemic discourse, they are limited in a number of ways that warrant further investigation. One limitation is that effects were only detected in the second design cycle of the simulation (i.e., in only two of the four conversations analyzed). A second limitation is that my study only examined data from one epistemic game. As such, it is possible that the effects found in my analysis may be unique to the *Nephrotex* simulation or to the content of engineering. A third limitation is that the design of my study did not account for other sources of data about student performance in the simulation such as individual notebook entries or the evaluation of their final products. Therefore, future research should explore whether: (1) APT affects collaborative outcomes in other epistemic games specifically, and/or other types of simulations more broadly, (2) the effects of APT differ by the focal content or the type of the simulation, and (3) accounting for the quality of group's final device and epistemic evidence in student notebooks would explain the observed effects of APT in student discourse.

Finally, my analysis suggested that differences in group's epistemic networks with regard to the use of APT were, in part, a function of more intensive discussion spurred on by the use of APT-style contributions in discourse. Future research should examine this dynamic in greater detail to provide better understandings about whether, and if so how, the introduction of APT-style contributions by a student, or students, in design meeting discourse encourages further APT-style contributions by other members of the group in subsequent moments of discourse. To do so, such research should consider much smaller units of analysis (i.e., 5-6 subsequent utterances in sequence) than were used in my own analysis (i.e., the entirety of the conversation). Relatedly, new research could investigate whether *specific* APT moves, or sequences of moves, that occur endogenously in conversation are more pivotal than others for triggering the kinds of intensive, critical interactions that lead to better epistemic integration.

Chapter 6

Research Question Three (RQ3)

Do students have a higher probability of reporting a positive change in their attitudes and perceptions toward engineering when they are in a group, or groups, that engage in higher proportions of Academically Productive Talk *in their discourse during design meetings (vs. those in a group, or groups, that engage in lower proportions)? What, if any, individual- and/or group-level characteristics are associated with a positive change in attitudes and perceptions toward engineering?*

6.1 Overview

As described in Chapter 3, students who participated in the *Nephrotex* virtual internship responded to survey questions administered before and after the simulation[38]. Questions in the survey included items that asked students to consider their associations with engineering careers, their perspectives and beliefs related to the work, characteristics and proclivities of engineers, and their commitment to pursuing a career in engineering. A subset of these questions (n=6) was identified for use in this study, and they were combined in three slightly different ways (see Table 6.1, below).

The first approach was to create a composite measure, comprised of all six survey items, that was intended to reflect a student's overall sense of self-efficacy (*SELFEFF*) related to a career in engineering. The second approach was to focus on the single question that indicated a student's level of commitment (*COMMIT*) to pursuing a career

[38] As presented in Chapter 3, my analysis of the missing data suggested that excluding students who did not complete post-survey items on the Confidence (87% response rate) or Commitment (89% response rate) measures would not bias the results of my final analysis.

in engineering. The third approach was to take the average of the student's scores on five survey items that asked about the student's confidence (*CONFID*) in his/her skills and abilities related to the work of engineers.

Table 6.1

Summary of survey items and their associated variables in this analysis

		Variable(s)		
Survey Item	**Item Scale**	**Self-Efficacy (*SELFEFF*)**	**Confidence (*CONFID*)**	**Commitment (*COMMIT*)**
A degree in engineering will allow me to get a job where I can use my talents and creativity.	1-5	✓	✓	
I feel confident in my ability to succeed in engineering.	1-5	✓	✓	
Someone like me can succeed in an engineering career.	1-5	✓	✓	
Creative thinking is one of my strengths.	1-5	✓	✓	
I am good at designing things.	1-5	✓	✓	
How committed are you to a career within engineering?	1-8	✓		✓

As a first step in addressing this research question, I examined whether there were differences in students' responses on the three summary variables before and after the simulation experience. Results using t-tests revealed that there were no significant differences (α-level, $p<.05$) between the means of students' pre- and post-scores on the self-efficacy, confidence, or commitment measures (see Table 6.2, below). This suggests that, without accounting for any other factors, students did not experience a *change* in their sense of self-efficacy, their commitment to pursuing a career in engineering, or in their confidence in their abilities as engineers, as a result of engaging in the simulation.

Table 6.2

Summary of t-test results comparing student pre- and post-survey scores

	Mean		**Standard Deviation**		**Test Statistics**		
Variable	**Pre-**	**Post-**	**Pre-**	**Post-**	**t**	**df**	***p*-value**
Self-Efficacy (PC1) (*standardized mean of 6 items)*	0.02	-0.02	1.67	1.90	0.3910	237	0.70
Confidence (*mean of 5 items; scale is 1=low to 5=high*)	4.08	4.07	0.49	0.53	0.0268	238	0.98
Commitment (*one item; scale is 1=low to 8=high*)	6.40	6.44	1.47	1.71	-0.5467	242	0.59

What these data also show is that both prior to *and* after playing *Nephrotex*, students, on average: (1) were more committed to pursuing a career in engineering than not (means of 6 on a scale from 1 to 8); (2) were fairly confident in their skills and abilities as engineers (means of 4 on a scale from 1 to 5); and (3) had generally strong levels of self-efficacy (i.e., both their confidence in their abilities as engineers *and* their commitment to pursuing a career in engineering).

Therefore, to answer this research question, I first analyzed student's pre- and post-survey responses to generate categorical outcome variables indicating if there was any positive change (1=yes, 0=no) in a student's self-efficacy (*CHNGE_SELFEFF*), confidence (*CHNGE_CONFID*), and/or commitment (*CHNGE_COMMIT*). Following this, I fit a series of logistic regression models to test the significance (α-level, $p<.05$) of participation in groups with higher APT use, controlling for particular individual characteristics (e.g., pre survey scores, level of experience, etc.), and group characteristics (e.g., equality of contribution, gender balance, etc.), on the probability that a positive change in a student's self-efficacy, confidence, and commitment toward engineering would occur.

6.2 Analysis of results

Results of logistic regression analysis to address research question three indicated that there is no evidence to suggest a relationship between students' participation in groups that engaged in higher proportions of *Academically Productive Talk* in design team meetings in *Nephrotex* and students' reporting a positive change in their confidence as an engineer, their commitment to pursuing a career in engineering, or their sense of self-efficacy in engineering. These findings persisted even when controlling for individual- and group-level characteristics, pre- and group-level survey scores, and other types of talk, in the regression models. Tables 6.3, 6.4, and 6.5 (below) summarize representative logistic regression analyses conducted for each of the three outcomes described above.

Table 6.3

Results of representative logistic regression analyses of a positive change in student's self-reported self-efficacy (SELFEFF) after the Nephrotex simulation (n=239)

Independent Variable	***b***	**se**	**z**	**P>z**	**95% Confidence Interval**	
Model One						
H1[39] Group APT use	-0.71	1.79	-0.39	0.694	-4.221	2.808
H2 Group APT use	1.76	1.65	1.07	0.285	-1.468	4.997
Constant	-0.19	0.88	-0.22	0.825	-1.921	1.532
Model χ^2 = 1.19 (p = 0.55)						
Pseudo R^2 = 0.0036						
Model Two						
H1 Group APT use	-1.91	2.05	-0.93	0.352	-5.935	2.113
H2 Group APT use	0.94	1.78	0.53	0.597	-2.546	4.428
Level of Experience	0.45	0.36	1.25	0.21	-0.253	1.146
Gender	0.02	0.32	0.06	0.954	-0.601	0.638
Constant	0.27	1.02	0.27	0.79	-1.722	2.264
Model χ^2 = 2.79 (p = 0.59)						
Pseudo R^2 = 0.0084						
Model Three						
H1 Group APT use	-1.87	2.15	-0.87	0.386	-6.083	2.350
H2 Group APT use	0.88	1.79	0.49	0.624	-2.628	4.379
H1 Group Contribution Equality	0.00	0.02	0.06	0.954	-0.037	0.039
H2 Group Contribution Equality	0.02	0.02	0.82	0.411	-0.027	0.065
H1 Group Gender Balance	0.02	0.72	0.03	0.978	-1.386	1.427
H2 Group Gender Balance	-0.47	0.78	-0.6	0.546	-1.992	1.054
Level of Experience	0.37	0.38	0.98	0.328	-0.369	1.104
Constant	0.45	1.29	0.35	0.729	-2.079	2.971
Model χ^2 = 3.88 (p = 0.79)						
Pseudo R^2 = 0.0117						

Note: The dependent variable in this analysis was coded so that 0 = no positive change and 1 = positive change.

[39] H1 = Design Cycle 1; H2 = Design Cycle 2

Table 6.4

Results of representative logistic regression analyses of a positive change in student's self-reported commitment (COMMIT) after the Nephrotex simulation (n=239)

Independent Variable	***b***	**se**	**z**	**P>z**	**95% Confidence Interval**	
Model One						
H1 Group APT use	1.69	1.93	0.87	0.382	-2.092	5.463
H2 Group APT use	0.86	1.76	0.49	0.624	-2.588	4.315
Constant	-1.75	0.96	-1.83	0.068	-3.637	0.129
Model χ^2= 1.2 (p = 0.55)						
Pseudo R^2 = 0.004						
Model Two						
H1 Group APT use	0.76	2.18	0.35	0.727	-3.511	5.035
H2 Group APT use	0.17	1.91	0.09	0.93	-3.569	3.903
Level of Experience	0.39	0.39	1.02	0.309	-0.365	1.153
Gender	0.24	0.35	0.7	0.486	-0.437	0.919
Constant	-1.60	1.10	-1.45	0.147	-3.755	0.560
Model χ^2= 2.8 (p = 0.59)						
Pseudo R^2 = 0.0093						
Model Three						
H1 Group APT use	1.33	2.29	0.58	0.563	-3.165	5.817
H2 Group APT use	0.07	1.93	0.03	0.972	-3.716	3.849
H1 Group Contribution Equality	-0.01	0.02	-0.68	0.497	-0.055	0.027
H2 Group Contribution Equality	0.04	0.02	1.76	0.078	-0.005	0.090
H1 Group Gender Balance	0.44	0.77	0.58	0.565	-1.068	1.956
H2 Group Gender Balance	-0.16	0.83	-0.19	0.85	-1.779	1.465
Level of Experience	0.19	0.41	0.47	0.637	-0.610	0.996
Constant	-2.01	1.39	-1.44	0.149	-4.739	0.720
Model χ^2 = 5.68 (p = 0.58)						
Pseudo R^2 = 0.0188						

Note: The dependent variable in this analysis was coded so that 0 = no positive change and 1 = positive change.

Table 6.5

Results of representative logistic regression analyses of a positive change in student's self-reported confidence (CONFID) after the Nephrotex simulation (n=234)

Independent Variable	***b***	**se**	**z**	**P>z**	**95% Confidence Interval**	
Model One						
H1 Group APT use	0.45	1.84	0.24	0.807	-3.149	4.045
H2 Group APT use	1.04	1.67	0.62	0.533	-2.237	4.321
Constant	-0.85	0.90	-0.94	0.348	-2.622	0.925
Model χ^2 = 0.52 (p = 0.77)						
Pseudo R^2 = 0.0016						
Model Two						
H1 Group APT use	-0.75	2.09	-0.36	0.721	-4.838	3.347
H2 Group APT use	0.20	1.81	0.11	0.912	-3.346	3.746
Level of Experience	0.47	0.37	1.27	0.203	-0.251	1.185
Gender	0.14	0.33	0.42	0.678	-0.503	0.774
Constant	-0.49	1.04	-0.47	0.636	-2.528	1.545
Model χ^2= 2.39 (p = 0.67)						
Pseudo R^2 = 0.0075						
Model Three						
H1 Group APT use	-1.16	2.20	-0.53	0.599	-5.473	3.159
H2 Group APT use	0.10	1.81	0.06	0.954	-3.452	3.660
H1 Group Contribution Equality	0.01	0.02	0.72	0.474	-0.025	0.054
H2 Group Contribution Equality	0.00	0.02	0.18	0.861	-0.042	0.050
H1 Group Gender Balance	-0.15	0.73	-0.21	0.835	-1.590	1.284
H2 Group Gender Balance	-0.70	0.79	-0.88	0.377	-2.253	0.853
Level of Experience	0.47	0.39	1.22	0.223	-0.286	1.227
Constant	0.22	1.31	0.17	0.868	-2.357	2.794
Model χ^2= 3.88 (p = 0.79)						
Pseudo R^2 = 0.0122						

Note: The dependent variable in this analysis was coded so that 0 = no positive change and 1 = positive change.

6.3 Discussion & Implications

This study set out to test two hypotheses related to the effects of *Academically Productive Talk* (APT) on a change in students' attitudes and perceptions in relation to engineering. First, I hypothesized that students who were members of a group, or groups, which used higher proportions of APT in their discourse would show a positive change in their attitudes toward engineering. I further hypothesized that individual- (e.g., level of experience, gender, degree of participation, etc.) and group-level (e.g., contribution equality, gender-balance, etc.) characteristics would be associated with such changes in student's attitudes. As presented above, my analysis found no evidence to suggest that students who participated in groups that engaged in more collaborative discourse, as evidenced by APT, reported a positive change in their attitudes in relation to engineering with regard to their confidence, commitment or self-efficacy.

There are a number of possible explanations for these null findings, as well as implications for future research. First, these findings are not surprising given that there were no significant differences, on average, between student's pre- and post-survey responses on these measures to begin with (see Table 6.1, above). However, my hypotheses were reasonable in the context of the research discussed in Chapter 2. In particular, prior studies have indicated that student's attitudes and perceptions at the onset of their experiences in game environments affect their experience in the game, the social interaction of groups, and collaborative activity (c.f., Bluemink et al., 2010; Kritzenberger, 2012; Giannakos, 2013; OECD, 2013). However, my findings cast doubt on the validity of my original hypothesis by suggesting that the relationship between student's attitudes and perceptions and the nature of their group's social interaction is *unidirectional*. Said another way, while prior research has established that attitudes and perceptions affect player experience and the nature of their social interaction, my findings indicate that the type of conversational experience students have, as codified in this study by APT, is not a strong enough factor to influence a change in their confidence, commitment or self-efficacy in relation to engineering.

Second, it is possible that collaborative discourse, *as codified by APT*, does not influence a change in student's attitudes about their relationship with the domain of interest. Future research could continue to test this assumption by, for instance, incorporating more refined and/or different measures of collaborative experience in groups to test whether *how* groups talk influences students' attitudes.

Third, these results may be interpreted to mean that the degree to which students experience, or participate in, groups that engage in more collaborative discourse, however codified, does not particularly influence their attitudes. Relatedly, is also possible that a change in attitudes, as they were measured in this study, take longer to appear in relation to a student's experience in such groups. This suggests that: (1) other factors influence a change in attitudes more directly, as prior research using data from *Nephrotex* has found (c.f., Arastoopour et al., 2012; 2013; 2014); and/or (2) the duration of the virtual simulation is not long enough for such a change to occur, if at all.

Fourth, it is also possible that my hypothesized relationship was not evident in this particular simulation, or with the specific field of practice simulated in the game (i.e., engineering). As such, future research using data from other simulated environments and/or in relation to other areas of study may identify a relationship between a student's participation in a group that uses more collaborative discourse and a change in their attitudes.

Finally, I may have obtained the results reported above because the measures I generated were not effective. Said another way, there may have been changes in student attitudes that were not detected by the subset of survey questions used to create the outcome variables for use in this study. For instance, there may be more effective ways to measure students' attitudes that would be more sensitive to change in relation to how they experience group discourse (i.e., the items used in this analysis may be ill-suited for this purpose). Alternately, although the survey questions used in the *Nephrotex* simulation have been validated in prior studies (see Arastoopour et al., 2014), using a reduced set of the survey items may have rendered the effects of interest in this study undetectable. Additionally, it is also possible that my subjective determination about which survey items to exclude (i.e., questions whose responses were more likely to reflect students' actual, inherent beliefs vs. perceived beliefs that may have arisen from external pressures, etc.) may have been flawed. As such, future studies could use a more rigorous approach to the selection of survey items against which to test my hypotheses.

Chapter 7

Conclusion

Based on the results and discussions of data analyses presented in Chapters 4, 5, and 6, the concluding chapter of this dissertation is organized as follows. I first present a summary of this study and the findings from each research question. Next, I address the potential threats to validity that should be considered when interpreting the findings presented in this study. Following this, I present a summary of the areas that future research should consider suggested by these findings. I then discuss the broad contributions this study makes to the field of research and practice. Finally, this chapter closes with brief concluding remarks.

7.1 Summary of study and findings

This study set out to examine the effects of collaborative discourse in a group problem-solving task within a serious game environment in order to better understand how to improve and extend the affordances these types of environments provide to support collaborative learning. Using data collected from a sample of 273 students, organized into 110 unique design groups, in the virtual simulation of engineering practice, *Nephrotex,* this study proposed three research questions, corresponding hypotheses, and a theoretical model to examine the relationships between epistemic (i.e., semantic) discourse, collaborative (i.e., syntactic) discourse, and student's attitudes and perceptions. To address my three research questions, I focused on one type of collaborative conversational interaction, *Academically Productive Talk* (APT), and its relationship with substantive, discipline-specific qualities of group discourse using

Epistemic Network Analysis (ENA). Prior to addressing the research questions, I applied a conversational-move coding scheme to the discourse data from the simulation after obtaining an appropriate level of inter-rater reliability with my co-rater. A discussion of findings and their implications related to Research Question 1 (RQ1), Research Question 2 (RQ2), and Research Question 3 (RQ3) were presented in Chapters 4, 5, and 6, respectively. In what follows, I briefly summarize these findings.

In Chapter 4, I presented and discussed my findings for RQ1, which hypothesized that there would be unique epistemic frame elements associated with different APT conversational moves in design team meeting discourse in the *Nephrotex* virtual internship. To test this hypothesis, I regressed each of the 20 possible epistemic outcome variables (i.e., semantic evidence of epistemic elements in student utterances) on the predictor variables drawn from the coding of discourse that characterized the syntactic contributions (i.e., conversational moves) found in design meeting discourse. I then calculated and interpreted the average marginal effects (i.e., practical effects) of all moves (predictors) found to be significantly associated with each of the epistemic elements (outcomes). Findings indicated that a number of APT moves, compared to other types of conversational moves, served different 'functional' roles in discourse with regard to yielding evidence of different types of epistemic outcomes. In particular, my findings showed that outcomes most uniquely associated with a number of APT moves (i.e., *Share Reasoning*, *Restate*, *Add More*, *Explain*, and *Challenge*) were those related to human-centered design constraints that students needed to consider in the completion of their design problem, namely those related to considerations of “the client” and “the consultant”. This finding is noteworthy because evidence of such considerations in student contributions were among the most *infrequent* epistemic elements evident in design team meeting discourse. In other words, the use of those APT moves in discourse were more likely than any other type of move to give rise to the inclusion of “the client” and “the consultant” in a student’s contribution. This suggested, for instance, that encouraging students to use the aforementioned APT moves in their discourse may support their development of more robust epistemic frames with regard to including these epistemic elements.

In Chapter 5, I presented and discussed my findings for RQ2, which hypothesized that groups with higher proportions of APT in their discourse would make connections in their discourse: (1) to more epistemic frame elements (i.e., larger networks, with a greater *variety* of connections); and (2) among more epistemic frame elements (i.e., denser networks, with a greater *number of connections*). To test these hypotheses, I conducted ENA, and qualitatively reviewed the discourse data, to examine the record of each group’s discourse as the students collaborated to solve a complex engineering design problem. My findings indicated groups that used more APT in their discourse achieved better knowledge integration, though this varied in terms of how and when such integration occurred. In particular, groups that used more APT-style contributions in their discourse *in the second design cycle* (i.e., Conversations 3 and 4) of the virtual internship made more critical, domain-specific (i.e., epistemic) connections in their discourse as they collaborated on the completion of their task. The differences in these connections were reflected in the density and size of group’s epistemic networks (as evidenced through ENA) and in the discourse data (reviewed qualitatively). More specifically: (1) greater APT use by groups in Conversation 3 resulted in a better integration of *the consultant* (i.e., his/her needs, interest, and expectations) and of *data analysis* (i.e., knowledge, skill, and epistemology) into their design thinking; and (2) greater APT use by groups in Conversation 4 resulted in a better integration of *the client* (i.e., the patient's wellbeing, health, comfort and/or safety).

Taken together, the findings for research questions one and two found empirical evidence of a relationship between *how* students talk (i.e., the syntactic function of contributions) and *what* they talk about (i.e., the semantic nature of those contributions) with regard to APT. In addition, this relationship was particularly salient with regard to whether the relatively low occurring epistemic elements of *the client* and *the consultant* were present in student contributions, and in turn, better integrated into student's design thinking. These findings suggested that there may be benefits to: (1) students learning, prior to playing *Nephrotex*, how to strategically use APT in their discourse as a way to interact with content and materials in more complex ways; and/or (2) simulation designers enhancing the in-game mentor scripts to include the explicit introduction of APT-style facilitation moves and/or ways of encouraging students to use such moves.

Finally, in Chapter 6 I presented and discussed my findings for RQ3 that hypothesized being in a group, or groups, which used higher proportions of APT in their discourse would affect a positive change in a student's attitudes toward engineering. To test this hypothesis, I fit a series of logistic regression models to test the significance of participation in groups with higher APT use, controlling for individual- and group-level characteristics, on the probability that a positive change in a student's self-efficacy, confidence, and commitment toward engineering would occur. My analysis found no evidence to suggest that students who participated in groups that engaged in more collaborative discourse, as evidenced by APT, during design team meetings in *Nephrotex* reported a positive change in their confidence as an engineer, their commitment to pursuing a career in engineering, or their sense of self-efficacy in engineering. These findings suggested that caution should be taken in claiming that engaging in effective collaboration, even in an authentic simulation, will give rise to increases in a student's confidence, commitment and self-efficacy in a profession.

7.2 Threats to validity

As with any investigation, my study raises questions about potential threats to validity, which give rise to caution in the interpretation of results. The first is that my findings are only representative of students who engaged in the *Nephrotex* simulation during the implementations from which I analyzed data. As such, my results may not be generalizable to the experience of students who have played *Nephrotex* in other implementations, to other epistemic games, to simulations in general, or to the population of engineering students. That said, the sample used in this study is representative of the target group for learning via *Nephrotex*. Second, I cannot rule out that there may have been other factors contributing to my results. Some of these may be factors in the dataset not used in this analysis due to restrictions of time and scope (e.g., isolated sequences of micro-interactions; notebook entries; final prototype evaluations) or that lie outside the game itself regarding individual students.

For instance, my analysis of group discourse was solely based on the record of what students contributed to the conversations and team design processes through the embedded chat interface. As such, the findings of this study do not account for the knowledge, insights, thoughts, perspectives, beliefs, etc. of students if they did not enter them into the chat interface during design team meeting. For example, if a student emailed their teammates individually, or engaged in off-line and/or in-person conversations, such communication was not accounted for in ENA. That said, these are unlikely factors to produce the effects described, as they potentially were equally present in the groups that used less APT in their discourse.

It is also possible that students who play interactive games or simulations in their free time are more comfortable using the format of synchronous online discourse, or even working collaboratively with others in an online format. Furthermore, I do not know the opinions of students regarding the efficacy of learning in this type of environment, nor their level of interest. It is therefore also possible that a student who believes collaboration is better suited in face-to-face contexts may have only participated to a minimal degree, or that some groups included students who were systematically disengaged and/or uninterested in the project.

Additionally, the qualitative nature of coding syntactic discourse may be subject to my own assumptions and biases, or those of my co-rater. I attempted to counteract the influence of this potential bias through the design of my study, as described in Chapter 3, by obtaining an acceptable level of inter-rater reliability, along with the recursive review of data with my co-rater in the analytical process. I also sought the insight and support of my ad hoc committee, HGSE faculty, and colleagues throughout the analytic process in order to test my assumptions and challenge my thinking.

Lastly, it is important to note two additional, and related, limitations - one methodological and the other interpretive – that future research should address. The first limitation has to do with a potential flaw in the analytical approach used to address research question one. In particular, although my analysis used logistic regression to model the relationship between APT moves and epistemic outcomes for each conversation (i.e., 1, 2, 3, and 4) in the sample, the analysis did not control for which conversation the student contribution occurred in. Neglecting to do so may have introduced a threat to the internal validity of my study. This methodological limitation, however, may also provide a plausible explanation for an interpretive limitation.

Although the findings for research questions one and two, considered side-by-side, presented broadly aligned evidence about the effects of APT in student discourse, they did not necessarily coincide at the level of *when* such effects were found. For instance, as presented in Chapter 5 (RQ2), groups that used higher proportions of APT in their discourse were found to better integrate "the client" into their design thinking in Conversation 4. However, as presented in Chapter 4 (RQ1), although the use of four APT moves (i.e., *Challenge, Share Reasoning, Add More, Explain*) were found to be uniquely associated with evidence of "the client" appearing in student contributions, they were *not* found to be so in Conversation 4, specifically.

On the one hand, this incongruity is not surprising because the analyses for research questions one two were conducted independently, and the findings from the former were not designed to frame the investigation of the latter (even though they utilized the same baseline data). That is, research questions one and two were formulated to address different gaps in the literature, to test different hypotheses, and utilized different methods. On the other hand, this limitation to making sense of the findings from each investigation, when they are considered concurrently, suggests that future research is warranted to better understand the relationship between *which* and *when* APT moves are predictive of particular epistemic outcomes, and *how* the use of those moves, in concert with other APT moves, influences the connections students make to and among different epistemic elements. For example, a future study that addresses the design flaw discussed above could leverage new findings related to research question one to refine and test, using ENA, whether, and if so how, subsets of APT moves affect epistemic integration in discourse. Further implications for future research are discussed in the following section.

7.3 Implications for future research

As summarized above, this study found that the prospects are rich for using APT as a means through which we can better understand *when*, *how*, and *what types of* knowledge students integrate in collaborative discourse. There are also a number of questions not resolved in this study because they were beyond the scope of this particular investigation. As such, this study sets the stage for future research about the ways in which collaborative interaction and problem solving in virtual settings can be used as a tool for learning, as well as the assessment of learning, especially with regard to three inter-related deeper learning competencies: communication, collaboration, and problem solving (i.e., *collaborative problem solving*).

To begin, the null findings reported in Chapter 6 suggest that future research should continue to explore whether collaborative experience in groups (i.e., *how* groups talk) affects a change in students' attitudes: (1) by using more refined and/or different measures of collaboration; and/or (2) in other types simulated environments; (3) in relation to other areas of study; (4) over a longer period of observation. For example, it may be that the period of "dosage" in this study was too short to facilitate changes in attitudes.

There are also a number of avenues, implied by my findings for research questions one and two, that design- or intervention-based research studies could examine. For instance, future work could test the efficacy of using APT-style contributions as a way to formatively assess student's ability to demonstrate collaborative problem solving and/or as a measure of group collaborative process and interaction in simulation-based learning environments. Relatedly, further studies should test whether, and if so how, the intentional use of APT scripts, or prompting students to use APT-style moves in their discourse, in such environments yields more and/or different types of knowledge integration, improves engagement and/or collaborative interaction.

Another area for further study has to do with exploring ways that both the semantic *and* the syntactic aspects of discourse in simulations and games could be codified in real-time so that differences in groups' discourse could trigger the activation of particular in-game or automated mentor scripts, re-directions, and/or interventions that could support the improvement of student's collaborative interaction and outcomes in a way that helps students to become better practitioners in the domain of interest. Finally, as discussed in Chapter 5, future research is warranted to better understand whether it is actually increases in the *quality* of APT use (i.e., increased use of specific, substantive moves, or patterns of such moves) in discourse that lead to better integration. As such, new research should investigate whether *specific* APT moves, or sequences of moves, that occur endogenously in conversation are more salient than others for triggering the kind of intensive, critical interactions that were found to lead to better epistemic integration in this study.

7.4 Contributions to the field

Notwithstanding the limitations presented above, findings from this study contribute to the expanding literature on the effectiveness of APT to support collaborative learning in general, and to a better understanding of the effects of APT beyond traditional measures of learning, namely the development of complex STEM thinking as exemplified in ENA. For instance, my specific focus on *Academically Productive Talk* (APT) in the *Nephrotex* simulation contributes in a number of ways because it found empirical evidence that more APT-style contributions in student discourse was related to students' integration, and building, of discipline-specific knowledge structures related to engineering design thinking and understanding. Additionally, this study extends and contributes to knowledge in the field because APT use overall, as well as specific APT moves, were found to have an effect: (1) in this type of simulated learning environment; and (2) relative to the specific content and context (i.e., engineering) of the simulation. These are important contributions because the efficacy of APT has not yet been specifically studied in game- and simulation-based environments. Furthermore, my findings also suggest that students can learn how to use/deploy APT-style interaction in simulated learning environments in order to support: (1) an increased presence of more critical and discipline-specific evidence; and (2) stronger integration of such evidence, in collaborative discourse.

More broadly, findings from this study can inform learning and research in the field on a number of fronts, including studies of the design, use, and efficacy of games and simulations for learning and assessment, as well as recent research on MOOC-based learning experiences (c.f., Rose et al., 2015). First, my findings can inform the ongoing research and development of technologies integrated into the architecture of games and simulations for learning (such as automated conversational agents) that are capable of shaping and observing discourse as it occurs to increase the probability that collaborative interaction will occur. This contribution is particularly salient given the recent and rapid developments in natural language processing/AI technologies that can deal with increasingly complex and inferential language (i.e., the shift from reliance on speech “recognition” toward the ability to interpret “language”).

Relatedly, my findings can inform current work that is focused on developing “stealth" applications (c.f., Shute, 2015; Shute & Rivera, 2013) that can track, monitor, and assess student conversational patterns to provide formative feedback in real time to individual participants, groups, and/or those in facilitative roles (i.e., teachers, in-game mentors, etc.). In addition, this research can support new understandings about the ways in which discourse can be measured against established outcomes to provide embedded self-monitoring strategies for participants through the use of in-game, real-time conversational “dash-boards” that can monitor engagement, decision-making, and ultimately, shape conversational behavior (Rose et al., 2015).

This research also contributes to the on-going and expanding efforts in the field to understand how the inter-related deeper learning competencies of collaboration, effective communication, and problem solving (i.e., *collaborative problem solving*) can be taught and assessed using a variety of digital, simulation and game-based technologies (USDoEd, 2010; NRC, 2012). This is so because APT was found to be an indication, broadly, of student's ability to enact important social and cognitive skills such as participation and cooperation, task regulation, knowledge building, perspective taking, and the evaluation of consequences, to name a few.

Lastly, the findings in this study can inform and contribute to practice in the field because this research expands evidence about the efficacy of APT by showing that its use not only fosters effective discourse and supports collaborative learning, but that it also supports the development and integration of complex STEM thinking. As such, practitioners in STEM disciplines are encouraged to consider introducing APT as a facilitative protocol in their classroom discourse. Another contribution, by extension, relates to high school and college programs that incorporate work-based learning and career pathways in their programming designed to enhance and support students' awareness and exploration of, and preparation for, successful career trajectories. Findings from this study provide insights into the benefits of including virtual internships, such as *Nephrotex*, in their learning progressions as a tool for the authentic and situated learning about, and assessment of, how students develop the ability to learn to think and work as professionals do, as well as how they are developing key deeper learning competencies increasingly emphasized as essential for success in work and life in the 21st century.

7.5 Concluding remarks

The design, focus, and central inquires of this study reflect the currents of an exciting and innovative time in the field of education, along with its many challenges *and* possibilities. The intersection of, and advancement in, the study and use of games for learning and assessment, especially with regard to deeper learning competencies, is informing the design of dynamic, rich, and immersive digital platforms that can 'situate learning' for students because they enable the use of discipline-specific tools and resources to consider, organize and employ domain-based knowledge to solve authentic, complex problems reminiscent of how professionals do, though in ways that are not normally feasible in typical "school" learning (Mislevy, 2010; Resnick, 1987; Brown et al., 1989; Shaffer, 2004). However, the rapid advances in technological possibilities also raise important questions about how to make meaning of the seas of data yielded by such environments that, in theory, are full of rich information about the ways and means by which students approach and solve such problems, and that are ripe to reveal important insights about the nature of student's transferable knowledge and how they acquire and employ a body of so-called 21st century skills (NRC, 2012). As such, the development of these technologies – whether for research or for practice - challenge, and provide opportunity for, the field to develop new analytics, scoring, reporting, and feedback mechanisms that can provide rich insights into both *what* and *how* students learn (Pellegrino and Quellmalz, 2010; Zapata-Rivera & Bauer, 2012; Scardamalia et al., 2012;).

In doing so, however, we should not only be concerned with developing the types of digital technologies and platforms we *think* we need now and that answer our immediate questions and concerns. Rather, we should orient research and design efforts to advance innovations in educational practice that we can grow into over the course of decades, and that will continuously challenge and transform our conceptions of the what, how, when, where, and why of learning, in all its forms (Quellmalz and Pellegrino, 2009; Behrens et al., 2012).

Of course, it remains to be seen whether the use of serious games and simulations in education will be a “disruptive innovation” (Christensen, 2003) or instigate a paradigm shift in educational practice with implications for “the structure of the group that practices the field” (Kuhn, 1996, p.18). It is possible, however, that to effectively “do school” under the auspices of a different vision for pedagogy and outcomes – such as the use of digital environments for learning like the one examined in this thesis that engages students in authentic, complex problem solving - educational practitioners will need to see the world they inhabit with new eyes, and effectively with new minds. The implications of this are substantial because as the types of knowledge and skills society values as outcomes in education continue to shift and evolve, coupled with changes in the characteristics and environments that learners bring with them to their school experience today, we must be continuously attuned to the challenge of developing, testing, and implementing new methods of teaching, learning, and assessment to meet these expectations.

Appendices

Appendix A

Summary of activities, by "room," for each phase of the virtual internship *Nephrotex* (shaded cells indicate activities/rooms used for analysis of discourse in this study). Modified from D'Angelo et al. (2011) and Golnaz Arastoopour, *Research Assistant* with Epistemic Games Group, personal communication, October 7, 2013.

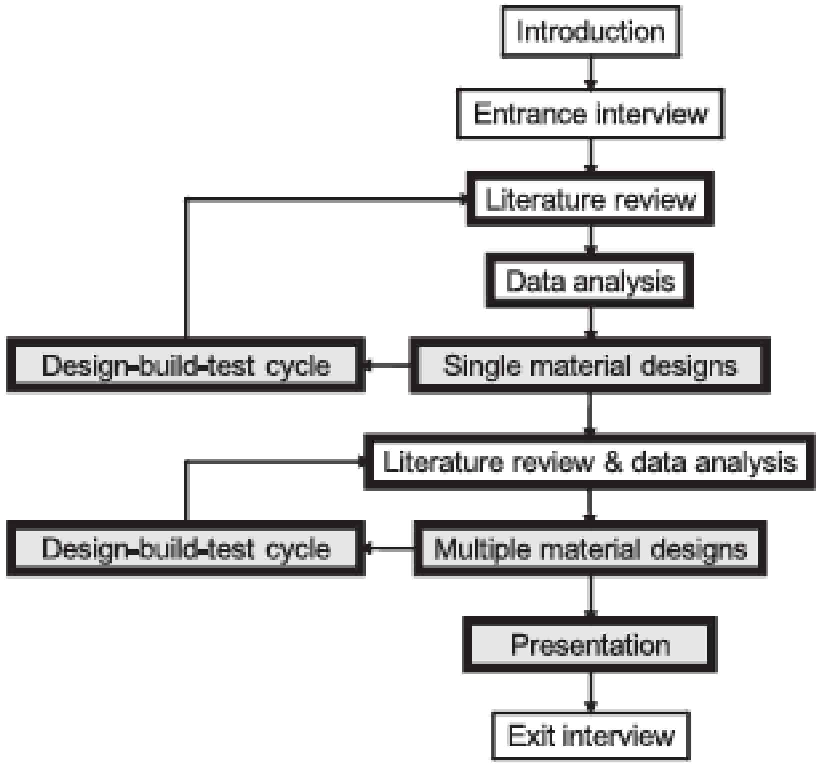
Phase	Room	Room Name & Activity Description (duration)
Introduction and Orientation	1	Entrance Interview (35 Min) • Introductions done by design advisors in chat • Students receive email to take entrance interview • Students take interview (interview may be difficult; students probably won't know many answers. It's ok and even encouraged for them to answer "I don't know" rather than blindly guess)
	2	Staff Page (10 Min) • Receive email • View other staff pages and create their own staff page • Guidelines: Write in 3rd person, use complete sentences, staff pages professional
Design Activity Cycle One	3	Dialysis Research (5 Min + HW) • Read two resources on Nephrotex website ("How dialysis works" and "Introduction to diffusion") • Read and cite two external resources not from the game • Summarize in notebook what was read • Should refer to "How to use notebook and shared space" if there are any questions on how to use the notebook • Other resources: "Hemodialytic filtration handbook"
	4	Graphing Cellulose Flux Data with Reflection Team Meeting (55 min) • Students should use the internal graphing tool • Need to fill out the table in the internal graphing tool by using resources mentioned in email (specifically the surfactant papers and benchmark tests) • Need to summarize the what they have found in an email as well • If not finished in class, should complete as homework
	5	Internal Consultants' Requests (35 min) • Receive email with information on all internal consultants • Summarize the internal consultants requests in notebook (Which attributes each internal consultant cares about & their limits on the attributes) • Should also suggest a surfactant for each internal consultant using information given today and from Room 4

Phase	Room	Room Name & Activity Description (duration)
	6	Component Relationships (20 min + HW) • Receive email explaining that their group is assigned to research one material • As a team and communicating through the chat, members will divide up research work by choosing one internal consultant's attributes to focus on for the given material (Each member should have two attributes to focus on. The attributes should be chosen by choosing an internal consultant (IC) as each IC cares about two different attributes). • Should read documents only pertaining to their material. Material is assigned by Alex (in-game supervisor) and includes: "Internal research on nanotube membrane reinforcement" and "device specifications" • Should record the affects of each device parameter that pertain the attributes of the IC that the student chose. Each student should record how "X" affects an attribute ("X" could be a different manufacturing process, surfactant, and so on.)
	7	Team Discussing and Ranking Attributes (30 Min) • Team should discuss and share literature findings from the homework • Team should then discuss and rank the 5 attributes in order of importance • Furthermore, they need to have good justification for the order that they chose • In the resource section there is a summary of the 5 attributes if needed • Email sent to Alex (the in-game supervisor) should be one email sent from the team
	8	Individual 5 Devices (20 Min + HW) • Members should individually make 5 devices or prototypes using FEEDS on the site • They should consider the internal consultants requests when making the prototypes • When selecting the different components, they should always select only the material they have been assigned to • Should try to create devices that satisfy all internal consultants
	9	Collaboration and Decision on Top 5 Designs with Reflection Team Meeting (40 Min) • Members should share their individual prototypes/designs with their team • Team should have a max of 25 different designs to choose from • Team needs to decide on the top 5 devices that they would like to receive data for (Need to create and submit a "Batch" of the top five devices) • In order for everyone in the team to receive the results, the batch must sent while using the "send from team" function in the email client
	10	Results from Experimental Tests (20 + HW) • Receive notification of results from top 5 devices in an email • Results appear on FEEDS page • Should also write 1-2 sentences on the performance of each device in their notebooks

Phase	Room	Room Name & Activity Description (duration)
Design Activity Cycle Two	11	Team Reassignment and 5 New Experimental Devices with Reflection Team Meeting (40 Min) • Receive email telling students their new teammates • New team should discuss strengths and weaknesses of each material • Team should then rank each material for each attribute (similar to the surfactant research in Room 4) • New team should propose 5 new devices using FEEDS
	12	Other Disciplines and Issues (10 + HW) • Identify two other engineering disciplines besides BME that would help construct the new dialyzer membrane • Choose two non-technical issues that might arise on design decisions (legal, environmental, social…) • Open-ended assignment that needs to be emailed to Alex
	13	Results of New Experiments (20 Min) • Receive notification of results from top 5 devices in an email • Results appear on FEEDS page • Write 1-2 sentences about performance of each device in their notebooks
	14	Final Design Selection with Reflection Team Meeting (30 Min + HW) • Discuss with team the experimental devices on chat • Should consider all devices (new devices as well as previous devices) and choose the best device, which will be the prototype that their team will present on • Write notebook entry discussing each parameter choice/why it was chosen (explaining which attributes each parameter effects)
Post-internship	15	Preparing Presentations (105 Min) • Students receive an email with the presentation guidelines and template • Poster must include all information outlined, but they can include additional slides or information • Posters should be finished outside of class.
	16	Prepare to Assessing Fellow Interns (5 Min + HW) • Audience should be paying attention to other group presentations as they will need to send a notebook entry discussing which team had the best device and which team had the strongest justifications.
	n/a	Poster Presentations (not virtual)
	17	Exit Interview and Bonuses (50 Min) • Receive email to take exit interview • Should answer questions the best of their ability • Should have a better understanding of the questions, but it is possible that they still might not know the answers • Students send an email ranking how well their group members did during the internship by assigning them bonus dollars.

Appendix B

Flow chart of the *Nephrotex* virtual internship progression as designed by *EGG/GAPS*. Reprinted from Chesler et al. (2013).



Appendix C

Engineering epistemic frame coding scheme applied to data by *EGG/GAPS*. Reproduced from Arastoopour et al. (2014) and Golnaz Arastoopour, *Research Assistant* with Epistemic Games Group, personal communication, October 7, 2013.

Epistemic Element Domain	Epistemic Element Sub-Code	Code Description	Examples from the data
Epistemology	of Data (E.Data)	Justifying decisions by using data such as graphs, results tables, numerical values, or research papers.	*All my devices have a biocompatibility of 87.78, I think that's the best you can get from Psf.*
	of Design (E.Design)	Justifying decisions using design terms/references such as device development, device specifications, ranking/priority of attributes, or tradeoffs in design.	*Well, we have to create five devices in the end. So maybe we can have 2% in a few, and a higher content in one or two as well as a compromise?*
	of Client (E.Client)	Justifying decisions by referring to the client's or patient's safety, health, wellbeing, or comfort.	*I agree with Rolando that biocompatibility is the most important because it takes into account safety of the patient as well.*
	of Internal Consultant (E.Consultant)	Justifying decisions stating or referring to the internal consultant's needs, wants, concerns, or preferences.	*I changed the percentage of CNT between the devices because it seemed as though the flux at 4% CNT was still somewhat in the consultant's range.*
Skill	of Data (S.Data)	The action of using numerical values, results, tables, graphs, or research papers.	*Oh, and I agree with using 2% for all of the devices, since it had great flux and reliability, if I remember right.*
	of Design (S.Design)	The action of design development, prioritizing, tradeoffs, and making design decisions.	*When deciding which ones to test, we took into account our attribute rankings as well as considering what good properties of certain processes canceled out others' shortcomings.*
	of Professionalism (S.Professional)	The action of using the company website, email, staff pages, or other internship related objects.	*Well we need to e-mail Alex our reasons for each device we submit.*
	of Collaboration (S.Collab)	The action of collaborating or participating in a team meeting.	*From last week's discussion it seemed like we were pretty decided on the devices though.*

Epistemic Element Domain	Epistemic Element Sub-Code	Code Description	Examples from the data
Identity	of Engineer (I.Engineer)	Identifying as an engineer or member of a team. Possession/ ownership of an engineering notebook, lab result, team, or company.	*Should we also share our notebook entries too? That basically says what we're going to discuss today too!*
	of Intern (I.Intern)	Identifying as an intern or staff member. Possession/ ownership of professional items.	*What do we do if we finished our staff page?*
Values	of Client (V.Client)	Valuing the client/patient or stating that their needs are important.	*I think it depends on which attributes are the most important to us and patients.*
	of Internal Consultants (V.Consultant)	Valuing the internal consultants' needs and thresholds or stating that their needs are important.	*My consultant, Rudy, set her price goal as under $100. The highest version of the CNT-PMMA is $7, so for me, any of these processes works well. I think we should focus on other attributes that have more of a drastic effect.*
Knowledge	of Data (K.Data)	Referring to numerical values, results tables, graphs, or research papers.	*My best device had cost of 110, biocompatibility of 76.67, flux of 19...*
	of Design (K.Design)	Referring to aspects of the device, prototype, experiment, or filtration membrane.	*So first and foremost, they must use the device.*
	of Client (K.Client)	Referring to the health, comfort, and safety of the client/patient.	*From the company's point of view, cost and marketability are large concerns, but for the patient [client], it needs to be biocompatible and reliable.*
	of Nanotechnology (K.CNT)	Referring to carbon nanotubes (CNT).	*I found that carbon nanotube content had no significant effects on biocompatibility*
	of Surfactants (K.Surfactant)	Referring to chemical surfactants (biological, hydrophilic, negative charge, and steric hindrance).	*The Hydrophilic Surfactant has some of the highest numbers according to desirability.*
	of Attributes (K.Attribute)	Referring to attributes: reliability, flux, biocompatibility, marketability, and cost.	*Cost was more of a secondary factor to consider.*
	of Manufacturing Process (K.Manufacturing)	Referring to manufacturing process (dry-jet, phase inversion, vapor deposition, polymerization).	*Dry-jet processing is cheaper.*
	of Materials (K.Materials)	Referring to materials (PMMA, polyrenalate (PRNLT), polysulfone (PSF), PESPVP, polyamide.	*We decided to use all the materials for our devices. That way, we can see how each perform after we test them.*

Appendix D

Pre- and post survey items (item # and text) from *Nephrotex*, organized by question type (scale).

Attitudes and Beliefs (1 = strongly disagree, 3= neutral, 5 = strongly agree)

1	A degree in engineering will allow me to get a job where I can use my talents and creativity.
2	Creative thinking is one of my strengths.
3	Engineering involved finding precise answers to problems.
4	Engineers are innovative.
5	Engineers contribute more to making the world a better place than people in most other occupations.
6	From what I know, engineering is boring. [NOTE: values reversed to read "is *not* boring"]
7	I am good at designing things.
8	I am studying engineering because I enjoy figuring out how things work.
9	I can succeed in an engineering curriculum.[a]
10	I enjoy problems that can be solved in different ways.
11	I enjoy taking liberal arts courses more than math and science courses. [NOTE: values reversed to read "I *do not* enjoy"…]
12	I enjoy the subjects of science and mathematics the most.
13	I expect that studying engineering will be rewarding.
14	I feel confident in my ability to succeed in engineering.
15	I feel like I know what an engineer does.
16	I intend to major in engineering next year.[a]
17	I like the professionalism that goes with being an engineer.
18	Someone like me can succeed in an engineering career.
19	Technology plays an important role in solving society's problems.
20	The future benefits of studying engineering are worth the effort.[a]
21	The future benefits of a career in engineering are worth the effort.[b]

Career Associations (1=Not At All, 8=A Great Deal)

1	Diverse interpersonal work environment (people you work with)
2	Diverse physical work environment (physical space where you work, e.g. office, lab, outdoors)
3	Healthy work-life balance
4	High Salary
5	Innovation/creativity
6	Intellectual stimulation
7	Opportunities to help other people
8	Opportunities to make the world a better place
9	Pleasing your family
10	Prestige
11	Working on teams

Commitment (1=no commitment, 8=fully committed)

1	How committed are you to a career within engineering?
2	How committed are you to a major within engineering?[a]

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[a] Item only included in survey for Novice students.
[b] Item only included in survey for Advanced students.

Appendix E

Conversational Move Coding Scheme.

APT-Facilitative Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Say more	Prompting someone to explain or elaborate on his/her thinking.	– *What are you hoping will be different using 20%CNT?* – *when you say blood cell rep, are you talking about the reactivity?*
Press for reasoning	Prompting someone to provide reasoning or justification or clarification about why he/she thinks, believes, says or claims something.	– *If reliability is so important, why would you choose the Ultra flux model?* – *Gary, why do you see number one as the better option?*
Revoice	Reframing what someone said, expressed, proposed, etc. in order to check/clarify understanding.	– *So are you saying we know reliability and flux are hand and hand?* – *i thought you said 2% CNT has a lower flux rate than 4%* – *Are you asking if I found anything about what the consultant said about manufacturing?*
Restate	Prompting someone to repeat something that someone else, or the group, said or decided on.	– *can we reaffirm what we decided one more time so i don't send him the wrong thing?* – *what was our order of importance?*
Add more	Prompting someone else or the group to add to or build upon something that was said, expressed, proposed, etc.	– *Can you add to what cari said?* – *What else should we consider about that idea?*
Agree/ Disagree	Prompting someone else or the group to agree or disagree with something that was said, expressed, proposed, etc. (includes testing for consensus on decisions or actions).	– *Does everyone agree that reliability is most important?* – *All in favor of device three say I*

APT-Facilitative Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Explain Other	Prompting someone else to explain why something someone said, expressed, proposed, etc. is right or wrong.	*Does anyone else think BCR is the most important?*
Challenge	Expressing or revealing a different conclusion or understanding of something that was said, expressed, proposed, etc.; often includes an acknowledgement of another's point of view.	– *True, but cost is our last priority* – *But the patient doesn't really care about how the product is represented as long as it works well*

APT-Conversational Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Say more	Explaining or elaborating on one's own thinking.	– *What im trying to sayis we have an opurtunity to sell the best and keep it at a resonable price* – *I don't think that biological surfactant is best, im just saying it was best in terms of blood cell reactivity*
[Share] reasoning	Providing reasoning or justification or clarification about why one thinks, believes, says or claims something; may or may not include "…because…"	– *I have BCR at the top because it most directly affect the health of the patient* – *Cost should be in the middle because although we want our product to be good, we also want to make a profit on it.* – *Regarding new devices, I think we should have a high CNT because that makes the devices more reliable*
Revoice	n/a: *only facilitative*	
Restate	Providing a summary of what someone else said, something the group decided, etc.	– *we decided the processes are so different that we wanted to test all of them, so we are testing hydrophilic with all 3, and then vapor and phase with negative surfactant* – *So, Nick's device has the lowest cost, the lowest reactivity for the devices at $110, high marketability, a good reliability and a midrange flux.*
Add more	Adding to or building upon something that someone else said, expressed, proposed, etc.; if someone is continuing their own line of thinking, it is coded as the utterance's relevant move (i.e., individuals do not add more to what they are saying).	– *And also that makes the device more susceptible to human error, making the device less reliable* – *Adding to what Brett said, blood cell reactivity's relevance is diminished if the initial flux is higher as well.* – *And by varying the levels of the nanotubes and the manufacturing processes we will get a good overview of the best product.*
Agree/ Disagree	Expressing agreement or disagreement with something that was said, expressed, proposed, etc. by an individual or the group (i.e., a proposal, course of action, etc.).	– *yes, I agree with him* – *that's my vote; etc.* – *I agree with Erin that cost and marketability should be lower*

APT-Conversational Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Explain Other	Providing an explanation about why something someone said, expressed, proposed, etc. is right or wrong.	– *No. since the fouling is measured in terms of time to 75% performance is there is a greater flux in that span of time the factor has a quality that offsets.* – *I agree on all of it but the last two. I think that cost should be last because if the marketability is better then the cost wouldn't matter as much.*
Challenge		n/a: *only facilitative*

Declaration Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Present	Explicit sharing of new content, data, information or learning gained through individual work, research, or examination of data or resources with the group.	– *Michelle Proctor is concerned about flux and reliability. She found that carbon nanotubes, and manufacturing process have a significant influence on the flux rate.* – *In my findings the blood cell reactivity was not affected by the manufacturing process or the amount of carbon nanotubes. It was only affected by the surfactant change and the biological did the best with blood cell reactivity* – *My previous team used polyrenalate with hydrophilic surfactant. With 10% nanotubes yielded the best reliability and a good flux rate*
POV	Expression or statement about what one thinks or believes about something (i.e., opinion or perspective) without justification.	– *I think it would be hard to convince a patient to risk discomfort even for a lower cost.* – *I think we need to bring marketability up further than 4* – *In my opinion, I think the attributes directly affecting patients are more important than the ones affecting the company*
Activity	Making a statement that conveys information to the group relevant to their process in relation to the task/work/learning/purpose of the conversation: a) about one's actions/activity; or b) that clarifies who's done something or what has happened prior to, or during, the conversation.	– *I had flux and reliability* – *I'm going to tweak my device by adding a higher CNT%* – *I'll make a notebook entry too and put it up on the shared space* – *I have all the information except for Samuel's reliability*
Inform	Making a statement that conveys information to the group relevant to their process in relation to the task/work/learning/purpose of the conversation: a) that clarifies meaning or understanding for others about a topic, fact or information already under discussion; or b) that expresses what one does or does not understand.	– *I got cost as the most important from adding them all up* – *I don't understand "x"* – *PAM is the hydrophilic* – *The most marketable of the surfactants is hydrophilic*

Proposal Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Process	Proposing: a) an approach to the task at hand, or a way to proceed; b) a way to go about working together as a group; or c) something to try that would manage the group process (i.e. turn taking).	– *we should go over our designs and see if any are the same that way we can limit some of those out right* – *Let's give Kyle some reasons for his email.* – *Has Dalton gone yet?* – *Maybe we could all pick our best prototype and then decide which consultant they would best match*
Role	Offering to take on a responsibility/role on behalf of the group (only coded at first instance of suggestion).	– *I can upload a notebook of five device proposals. Then you guys can take a look at them and see what you want to change?* – *I'll type up justifications for all of these* – *I can talk about mine first*
Response	Proposing how the group's thinking /ideas about content, solutions, etc. will be represented or submitted, *without* justification (this would be "Share Reasoning").	– *how about we submit 2 dry-jet devices and 2 phase devices...and then one control* – *I say we should include…* – *Ok – put that before cost maybe?* – *Perhaps we can tentatively say that…* – *I think we should mention how…*
Approach	Proposing a skills-based or content-relevant strategy about how to go about doing something related to the completion of the task (i.e. analytical or experimental in nature, not group-process).	– *Should we try to vary different things?* – *How bout we use one of the experiments as a control for the other variable* – *Can we narrow things down by eliminating a process, carobn nanotube %age., or surfactant?*

Eliciting Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Pose	Asking a question about what someone else, or others, think about something (i.e. an idea, a proposal, an action, etc.).	– *So now that we have the atributes ranked, which kind of surficant do you think we should go with?* – *What does everyone else think of this?* – *Does anyone think cost and marketability could be switched?* – *Are there any other traits that people feel rank very highly, other than blood cell reactivity?* – *So what should be next?*
Process	Drawing out the ideas/thinking of others about: a) an approach to the task at hand, or a way to proceed; b) a way to go about working together as a group; or c) something to try that would manage the group process (i.e. turn taking).	– *so do you want to "rank " things based on current importance or importance of improvement* – *How do we want to start the discussion?* – *Do you guys want to discuss about previous experimental devices we had?* – *Who wants to type this up?*
Clarify	Asking a question to someone, or the group: a) to gain clarity about: 1) what something means (i.e. facts, information, data, a process, etc.); or 2) who did something related to the task/work of the group. b) that expresses that one does not understand something (skill-related, fact-based, etc.) or about one's uncertainty.	– *What position was flux again?* – *But my question is, does the blood cell reactivity endanger the patient or is it just uncomfortable?* – *Does carbon nanotubes affect blood reactivity?* – *I got kind of confused when I was reading about the carbon fiber content. Does increasing it make the flux higher?* – *Anyone happen to get the other part finished?* – *Who looked at cost?*

Administrative Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
State	1) Statements about the process/approach/workflow/etc. that <u>should</u> be engaged in in terms of requirements, expectations, etc. of the activity/task; or 2) Statements that explain, clarify or convey technical information or details that: a) support engagement in the activity/task because they help others know who, what or where things "are"; or b) convey information about "stuff" that has happened (i.e., new email received, etc.).	– *Yes, I see we need to create 5 expirimental devices; we're supposed to discuss how manufacturing, surfactant and cnt affect the specific attributes* – *I just got a response from Alex. Our results are ready.* – *It's in the shared folder; You can find it in the report* – *I don't think Matt's on; Is everybody on yet?*
Pose	1) Questions about the process/approach/workflow/etc. that <u>should</u> be engaged in in terms of requirements, expectations, etc. of the activity/task; or 2) Questions that seek an explanation or clarification about technical information or details that will: a) support engagement in the activity/task through knowing who, what or where things "are"; or b) yield information about "stuff" that has happened (i.e., new email received, etc.).	– *Should we be expecting another email from Alex?* – *Are we just creating a device that will meet the needs of any customer?* – *Do we each have to come up with 5 devices?* – *Any idea how to send the experimental devices?*
Action	Statements that convey that one will, should/should have or has done something related to the "technical" business of the activity/task.	– *I will email the ranking of the 5* – *I shared my report; I will share [post] my report* – *I was still typing in the notebook;I'm still reading each report* – *I just generated a new batch called team with the devices*

"Other" Conversational Moves		
Move	**Description/Indicators**	**Examples from the data**
Enter	Presence and departure statements	– *I'm here; hello; hey everyone* – *Signing off; have a nice day*
Express	1) Generic responses to suggestions, role proposals, etc. (not agree/disagree) 2) Comments of appreciation, thanks, etc.	*OK; fine by me; go ahead; ready; thanks; looks great; I don't either; sure, I can do that; thanks!; etc.*
Repair	Utterances that correct (i.e, spelling, mis-types) or retract a previous utterance.	– **too high [to correct "too low"]* – **BCR rather [to correct "BCM"]*
State	1) Statements that are off-task and/or irrelevant to the purpose of the activity/discussion, including small talk, jokes and commentaries on behavior, sharing of personal information, etc. 2) Accidental and/or nonsensical entries (different than repair)	– *Adam is at a career fair* – *I have two midterms this week* – *Num=262 422 0488; my email is "x"* – *Just switched to another computer* – *"++/*/*"*

Sources consulted for *Academically Productive Talk* (APT) moves: Michaels et al., 2008; Adamson et al., 2012.

Other sources consulted: Morgan et al. 2013; Bluemink et al., 2010; Hartung & Wilson, in press; Cakir et al., 2005; Cheng, 2014; Soller et al., 1998; Kapur & Kinzer, 2007; Berkowitz & Gibbs, 1983; Kittleson & Southerland, 2004.

Appendix F

Table F1

Summary of the frequency of Coder A and Coder B's conversational move coding within each functional move category for each utterance in the inter-rater reliability dataset (n=7844)

		Coder B								
		Admin.	**APT-C**	**Declare**	**Elicit**	**APT-F**	**Other**	**Propose**	**Combine**	**Total**
Coder A	**Admin.**	576	7	9	10	1	14	14	2	**633**
	APT-C	7	1,734	113	10	19	41	28	25	**1,977**
	Declare	9	75	1,332	9	13	16	11	5	**1,470**
	Eliciting	12	3	7	756	12	5	33	7	**835**
	APT-F	2	41	16	32	282	2	8	2	**385**
	Other	9	9	2	2	0	1,214	1	2	**1,239**
	Proposal	21	31	45	20	4	7	681	5	**814**
	Combine	0	15	11	3	1	5	6	450	**491**
	Total	**636**	**1,915**	**1,535**	**842**	**332**	**1,304**	**782**	**498**	**7,844**

Table F2

Summary of inter-rater reliability statistics for each functional move category and each conversational move within each functional category

Conversational Category/*Move*	Agreement	Expected Agreement	Kappa	Standard Error	Z	Prob>Z
Administrative	98.51%	85.13%	0.90	0.0113	79.68	0
State	99.26%	93.86%	0.88	0.0113	78.2	0
Pose	99.49%	93.58%	0.92	0.0113	81.82	0
Action	99.47%	96.96%	0.83	0.0113	73.34	0
APT -Conversational	94.59%	62.69%	0.86	0.0113	75.75	0
Say More	98.90%	97.06%	0.62^	0.011	56.65	0
Share Reasoning	98.57%	90.61%	0.85	0.0113	75.32	0
Restate	98.97%	95.87%	0.75^	0.0111	67.47	0
Add More	98.99%	97.35%	0.62^	0.0112	55.11	0
Agree/Disagree	98.25%	80.10%	0.91	0.0113	81.03	0
Explain	98.24%	93.24%	0.74^	0.0112	65.84	0
Declaration	95.65%	69.03%	0.86	0.0113	76.16	0
Present	99.05%	93.57%	0.85	0.0113	75.72	0
POV	97.99%	90.23%	0.79^	0.0112	70.63	0
Activity	99.35%	94.14%	0.89	0.0113	79.04	0
Inform	97.45%	86.17%	0.82	0.0113	72.49	0
Eliciting	97.90%	80.91%	0.89	0.0113	78.81	0
Pose	98.90%	92.93%	0.84	0.0113	74.99	0
Process	99.20%	94.38%	0.86	0.0113	76.24	0
Clarify	98.72%	92.21%	0.84	0.0113	74.24	0
APT- Facilitative	98.05%	91.27%	0.78^	0.0113	68.97	0
Say More	99.66%	98.60%	0.76^	0.0112	67.14	0
Press for Reasoning	99.85%	98.84%	0.87	0.0112	77.34	0
Revoice	99.73%	99.31%	0.62^	0.0107	57.65	0
Restate	99.85%	99.49%	0.70^	0.0113	62.11	0
Add More	100.00%	99.97%	1.00	0.0113	88.83	0
Agree/Disagree	99.68%	97.93%	0.85	0.0113	75.23	0
Explain	99.99%	99.89%	0.89	0.0112	79.45	0
Challenge	99.10%	96.97%	0.70^	0.0112	62.82	0

Conversational Category/*Move*	**Agreement**	**Expected Agreement**	**Kappa**	**Standard Error**	**Z**	**Prob>Z**
Other	98.53%	72.83%	0.95	0.0113	83.83	0
Enter	99.86%	91.51%	0.98	0.0113	87.37	0
Express	98.95%	87.57%	0.92	0.0113	81.33	0
Repair	99.81%	97.78%	0.91	0.0112	81.28	0
State	99.46%	92.53%	0.93	0.0112	82.53	0
Proposal	97.02%	81.72%	0.84	0.0113	74.13	0
Process	98.68%	91.04%	0.85	0.0113	75.77	0
Role	99.72%	96.56%	0.92	0.0113	81.64	0
Response	98.35%	93.84%	0.73^	0.0112	65.18	0
Approach	99.76%	99.05%	0.75^	0.0112	66.27	0
Combine	98.87%	88.19%	0.90	0.0113	80.06	0

^ Indicates a *substantial* (>.061 & <0.81), rather than *near perfect*, level of agreement between raters.

Appendix G. Summary statistics of the distribution of conversational moves in the sample, in each design cycle, and in each conversation.

	Sample		Design Cycle 1						Design Cycle 2					
			Convo 1		Convo 2		Total		Convo 1		Convo 2		Total	
Talk Type Category/*Code*	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**
APT-Conversational	**5207**	**34.56%**	**1650**	**40.40%**	**1813**	**39.24%**	**3463**	**39.79%**	**948**	**22.24%**	**796**	**37.89%**	**1744**	**27.40%**
Say More	233	1.55%	91	2.23%	78	1.69%	169	1.94%	49	1.15%	15	0.71%	64	1.01%
Share Reasoning	1011	6.71%	369	9.04%	322	6.97%	691	7.94%	183	4.29%	137	6.52%	320	5.03%
Restate	626	4.15%	96	2.35%	274	5.93%	370	4.25%	165	3.87%	91	4.33%	256	4.02%
Add More	301	2.00%	98	2.40%	110	2.38%	208	2.39%	48	1.13%	45	2.14%	93	1.46%
Agree/Disagree	2283	15.15%	743	18.19%	812	17.58%	1555	17.87%	401	9.41%	327	15.56%	728	11.44%
Explain	753	5.00%	253	6.19%	217	4.70%	470	5.40%	102	2.39%	181	8.61%	283	4.45%
APT-Facilitative	**902**	**5.99%**	**350**	**8.57%**	**265**	**5.74%**	**615**	**7.07%**	**125**	**2.93%**	**162**	**7.71%**	**287**	**4.51%**
Say More	131	0.87%	49	1.20%	37	0.80%	86	0.99%	35	0.82%	10	0.48%	45	0.71%
Press for Reasoning	119	0.79%	67	1.64%	40	0.87%	107	1.23%	4	0.09%	8	0.38%	12	0.19%
Revoice	77	0.51%	26	0.64%	21	0.45%	47	0.54%	13	0.30%	17	0.81%	30	0.47%
Restate	57	0.38%	8	0.20%	22	0.48%	30	0.34%	15	0.35%	12	0.57%	27	0.42%
Add More	1	0.01%	1	0.02%	0	0.00%	1	0.01%	0	0.00%	0	0.00%	0	0.00%
Agree/Disagree	201	1.33%	78	1.91%	62	1.34%	140	1.61%	18	0.42%	43	2.05%	61	0.96%
Explain	5	0.03%	5	0.12%	0	0.00%	5	0.06%	0	0.00%	0	0.00%	0	0.00%
Challenge	311	2.06%	116	2.84%	83	1.80%	199	2.29%	40	0.94%	72	3.43%	112	1.76%
APT (combined)	**6109**	**40.54%**	**2000**	**48.97%**	**2078**	**44.98%**	**4078**	**46.85%**	**1073**	**25.17%**	**958**	**45.60%**	**2031**	**31.91%**

	Sample		Design Cycle 1						Design Cycle 2					
			Convo 1		Convo 2		Total		Convo 1		Convo 2		Total	
Talk Type Category/*Code*	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**	**n**	**Percent**
Administrative	**1533**	**10.17%**	**404**	**9.89%**	**457**	**9.89%**	**861**	**9.89%**	**415**	**9.73%**	**257**	**12.23%**	**672**	**10.56%**
Statement	594	3.94%	149	3.65%	174	3.77%	323	3.71%	141	3.31%	130	6.19%	271	4.26%
Pose	624	4.14%	170	4.16%	157	3.40%	327	3.76%	193	4.53%	104	4.95%	297	4.67%
Action	315	2.09%	85	2.08%	126	2.73%	211	2.42%	81	1.90%	23	1.09%	104	1.63%
Declaration	**3639**	**24.15%**	**838**	**20.52%**	**790**	**17.10%**	**1628**	**18.70%**	**1503**	**35.26%**	**508**	**24.18%**	**2011**	**31.60%**
Present	690	4.58%	193	4.73%	118	2.55%	311	3.57%	344	8.07%	35	1.67%	379	5.96%
POV	967	6.42%	365	8.94%	280	6.06%	645	7.41%	158	3.71%	164	7.81%	322	5.06%
Activity	626	4.15%	131	3.21%	159	3.44%	290	3.33%	288	6.76%	48	2.28%	336	5.28%
Inform	1356	9.00%	149	3.65%	233	5.04%	382	4.39%	713	16.73%	261	12.42%	974	15.30%
Eliciting	**1883**	**12.50%**	**403**	**9.87%**	**598**	**12.94%**	**1001**	**11.50%**	**633**	**14.85%**	**249**	**11.85%**	**882**	**13.86%**
Pose	632	4.19%	165	4.04%	265	5.74%	430	4.94%	119	2.79%	83	3.95%	202	3.17%
Process	474	3.15%	111	2.72%	165	3.57%	276	3.17%	181	4.25%	17	0.81%	198	3.11%
Clarify	777	5.16%	127	3.11%	168	3.64%	295	3.39%	333	7.81%	149	7.09%	482	7.57%
Proposal	**1904**	**12.64%**	**439**	**10.75%**	**697**	**15.09%**	**1136**	**13.05%**	**639**	**14.99%**	**129**	**6.14%**	**768**	**12.07%**
Process	841	5.58%	233	5.71%	261	5.65%	494	5.68%	295	6.92%	52	2.48%	347	5.45%
Role	285	1.89%	109	2.67%	109	2.36%	218	2.50%	64	1.50%	3	0.14%	67	1.05%
Response	585	3.88%	92	2.25%	218	4.72%	310	3.56%	219	5.14%	56	2.67%	275	4.32%
Approach	193	1.28%	5	0.12%	109	2.36%	114	1.31%	61	1.43%	18	0.86%	79	1.24%
non-APT moves (combined)	**8959**	**59.46%**	**2084**	**51.03%**	**2542**	**55.02%**	**4626**	**53.15%**	**3190**	**74.83%**	**1143**	**54.40%**	**4333**	**68.09%**
Total	**15068**	**100%**	**4084**	**100%**	**4620**	**100%**	**8704**	**100%**	**4263**	**100%**	**2101**	**100%**	**6364**	**100%**

Appendix H

Summary tables of AME results of independent variables (conversational moves) from logit models, by epistemic outcome (dependent variable) and level of model (i.e. Conversation, Design Cycle, Sample) for low (Table H1), moderate (Table H2), and high (Table H3) evidence epistemic elements in *Nephrotex* discourse. APT moves are highlighted in red.

Table H1

AME results for epistemic elements with a ***low*** *frequency of evidence in* Nephrotex *discourse.*

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
Epistemology of Client						
Conversation 2						
APT-C: Share Reasoning	0.006	0.002	2.53	0.011	0.001	0.010
Conversation 3						
APT-F: Challenge	0.013	0.004	3.01	0.003	0.004	0.021
APT-C: Share Reasoning	0.013	0.004	3.32	0.001	0.005	0.021
Design Cycle 1						
APT-C: Restate	0.026	0.009	2.84	0.005	0.008	0.044
APT-C: Say More	0.031	0.009	3.33	0.001	0.013	0.049
APT-C: Add More	0.037	0.008	4.7	0	0.022	0.053
APT-C: Explain	0.044	0.006	7.43	0	0.033	0.056
APT-F: Challenge	0.046	0.007	6.8	0	0.033	0.060
APT-C: Share Reasoning	0.060	0.006	10.3	0	0.049	0.072
Design Cycle 2						
APT-C: Explain	0.014	0.004	3.21	0.001	0.006	0.023
APT-F: Challenge	0.015	0.005	3.25	0.001	0.006	0.025
APT-C: Share Reasoning	0.017	0.005	3.63	0	0.008	0.027
Sample of Conversations						
APT-C: Restate	0.017	0.006	2.78	0.005	0.005	0.029
APT-C: Say More	0.023	0.006	3.64	0	0.011	0.035
APT-C: Add More	0.027	0.005	5.14	0	0.017	0.038
APT-C: Explain	0.032	0.004	8.36	0	0.025	0.040
APT-F: Challenge	0.034	0.004	7.88	0	0.026	0.043
APT-C: Share Reasoning	0.044	0.004	11.02	0	0.036	0.051
Knowledge of Client						
Conversation 1						
ELICIT: Clarify	0.166	0.048	3.43	0.001	0.071	0.261
ELICIT: Pose	0.177	0.044	3.98	0	0.090	0.264
DECLARE: Present	0.180	0.043	4.14	0	0.095	0.265
SUGGEST: Response	0.181	0.049	3.73	0	0.086	0.276
APT-C: Restate	0.194	0.046	4.19	0	0.103	0.284
DECLARE: Inform	0.209	0.042	4.94	0	0.126	0.292
DECLARE: POV	0.214	0.040	5.39	0	0.136	0.292
APT-C: Say More	0.222	0.044	5.05	0	0.136	0.308
APT-F: Revoice	0.253	0.050	5.08	0	0.155	0.350
APT-C: Add More	0.269	0.041	6.59	0	0.189	0.350
APT-F: Challenge	0.286	0.040	7.14	0	0.208	0.365
APT-C: Explain	0.294	0.039	7.54	0	0.217	0.370
APT-C: Share Reasoning	0.320	0.039	8.3	0	0.244	0.395
APT-F: Explain	0.339	0.061	5.57	0	0.220	0.459

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
Conversation 2						
APT-C: Share Reasoning	0.009	0.003	3.24	0.001	0.004	0.015
Conversation 3						
APT-C: Add More	0.016	0.006	2.58	0.01	0.004	0.028
APT-C: Explain	0.017	0.005	3.7	0	0.008	0.026
APT-F: Challenge	0.018	0.005	3.32	0.001	0.007	0.028
APT-C: Share Reasoning	0.018	0.004	4.2	0	0.010	0.027
Design Cycle 1						
ELICIT: Pose	0.042	0.014	2.94	0.003	0.014	0.070
APT-C: Restate	0.049	0.017	2.93	0.003	0.016	0.081
DECLARE: Present	0.058	0.014	4.24	0	0.031	0.084
DECLARE: Inform	0.059	0.013	4.67	0	0.034	0.083
DECLARE: POV	0.071	0.010	6.91	0	0.051	0.091
APT-C: Say More	0.071	0.015	4.89	0	0.043	0.100
APT-F: Revoice	0.089	0.019	4.58	0	0.051	0.127
APT-C: Add More	0.097	0.012	8.45	0	0.075	0.120
APT-F: Challenge	0.109	0.011	10.14	0	0.088	0.130
APT-C: Explain	0.114	0.010	11.91	0	0.095	0.132
APT-C: Share Reasoning	0.126	0.009	13.65	0	0.108	0.144
APT-F: Explain	0.157	0.028	5.53	0	0.101	0.212
Design Cycle 2						
APT-F: Challenge	0.015	0.004	3.56	0	0.007	0.023
APT-C: Explain	0.016	0.004	4.57	0	0.009	0.023
APT-C: Share Reasoning	0.019	0.004	5.09	0	0.012	0.027
Sample of Conversations						
DECLARE: POV	0.033	0.005	6.22	0	0.023	0.044
APT-C: Say More	0.036	0.009	4.1	0	0.019	0.053
APT-F: Revoice	0.043	0.012	3.62	0	0.020	0.067
APT-C: Add More	0.055	0.006	8.77	0	0.042	0.067
APT-F: Challenge	0.060	0.006	10.91	0	0.049	0.071
APT-C: Explain	0.063	0.005	13.74	0	0.054	0.072
APT-C: Share Reasoning	0.074	0.004	16.51	0	0.065	0.083
APT-F: Explain	0.098	0.018	5.31	0	0.062	0.134
Values of Client						
Design Cycle 1						
APT-C: Explain	0.019	0.004	4.91	0	0.012	0.027
APT-C: Add More	0.021	0.005	4.33	0	0.011	0.030
APT-F: Challenge	0.022	0.005	4.71	0	0.013	0.031
APT-C: Share Reasoning	0.027	0.004	7.19	0	0.020	0.034
Sample of Conversations						
DECLARE: POV	0.009	0.003	3.22	0.001	0.004	0.015
APT-C: Say More	0.012	0.004	2.87	0.004	0.004	0.020
APT-C: Explain	0.014	0.003	5.26	0	0.009	0.020
APT-C: Add More	0.016	0.003	4.97	0	0.010	0.023
APT-F: Challenge	0.017	0.003	5.47	0	0.011	0.023
APT-C: Share Reasoning	0.020	0.003	7.25	0	0.015	0.026
Epistemology of Consultant						
Conversation 1						
APT-C: Share Reasoning	0.013	0.005	2.58	0.01	0.003	0.022
DECLARE: Present	0.027	0.005	5.15	0	0.017	0.037

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
Conversation 2						
APT-C: Share Reasoning	0.030	0.006	5.3	0	0.019	0.040
Conversation 3						
APT-C: Share Reasoning	0.019	0.005	3.79	0	0.009	0.029
APT-F: Press Reasoning	0.035	0.012	2.85	0.004	0.011	0.059
Conversation 4						
APT-C: Share Reasoning	0.041	0.008	4.86	0	0.024	0.057
Design Cycle 1						
ELICIT: Pose	-0.023	0.012	-1.99	0.047	-0.046	0.000
DECLARE: POV	-0.022	0.010	-2.3	0.022	-0.042	-0.003
APT-C: Share Reasoning	0.013	0.004	3.15	0.002	0.005	0.021
DECLARE: Present	0.018	0.005	3.68	0	0.008	0.028
Design Cycle 2						
APT-C: Share Reasoning	0.027	0.004	6.24	0	0.019	0.036
Sample of Conversations						
ADMIN: Pose	-0.036	0.015	-2.47	0.014	-0.064	-0.007
SUGGEST: Response	-0.035	0.015	-2.4	0.016	-0.063	-0.006
ELICIT: Clarify	-0.029	0.010	-2.78	0.006	-0.049	-0.008
ELICIT: Process	-0.022	0.010	-2.15	0.032	-0.043	-0.002
DECLARE: POV	-0.021	0.007	-2.86	0.004	-0.036	-0.007
DECLARE: Activity	-0.020	0.009	-2.29	0.022	-0.036	-0.003
ELICIT: Pose	-0.016	0.007	-2.2	0.028	-0.031	-0.002
DECLARE: Inform	-0.014	0.005	-2.79	0.005	-0.023	-0.004
DECLARE: Present	0.009	0.004	2.28	0.022	0.001	0.016
SUGGEST: Approach	0.014	0.006	2.27	0.023	0.002	0.027
APT-C: Share Reasoning	0.015	0.003	5.16	0	0.009	0.021
Values of Consultant						
Conversation 3						
APT-C: Share Reasoning	0.010	0.003	3.03	0.002	0.003	0.016
APT-C: Add More	0.011	0.005	2.22	0.026	0.001	0.020
Conversation 4						
APT-C: Share Reasoning	0.015	0.006	2.47	0.013	0.003	0.027
SUGGEST: Process	0.017	0.007	2.4	0.016	0.003	0.030
ELICIT: Process	0.020	0.009	2.2	0.027	0.002	0.037
SUGGEST: Approach	0.024	0.008	3.02	0.002	0.009	0.040
Design Cycle 1						
DECLARE: Present	0.008	0.003	2.66	0.008	0.002	0.014
SUGGEST: Process	0.009	0.002	3.51	0	0.004	0.014
SUGGEST: Approach	0.016	0.004	4.18	0	0.008	0.023
Design Cycle 2						
APT-C: Share Reasoning	0.011	0.003	3.85	0	0.005	0.017
SUGGEST: Approach	0.014	0.004	3.53	0	0.006	0.021
Sample of Conversations						
APT-C: Share Reasoning	0.006	0.002	3.28	0.001	0.003	0.010
SUGGEST: Process	0.007	0.002	3.79	0	0.004	0.011
SUGGEST: Approach	0.015	0.003	5.44	0	0.009	0.020

Table H2

*AME results for epistemic elements with a **moderate** frequency of evidence in* Nephrotex *discourse*

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
Epistemology of Data						
Conversation 1						
DECLARE: POV	0.060	0.022	2.74	0.006	0.017	0.103
DECLARE: Inform	0.072	0.028	2.6	0.009	0.018	0.127
APT-C: Restate	0.074	0.032	2.29	0.022	0.011	0.138
ELICIT: Pose	0.075	0.026	2.87	0.004	0.024	0.127
ELICIT: Process	0.079	0.030	2.65	0.008	0.020	0.137
ADMIN: Pose	0.089	0.024	3.64	0	0.041	0.136
APT-F: Press Reasoning	0.096	0.033	2.92	0.003	0.032	0.160
APT-C: Add More	0.097	0.028	3.46	0.001	0.042	0.153
ADMIN: State	0.119	0.022	5.36	0	0.076	0.163
APT-C: Say More	0.120	0.026	4.64	0	0.069	0.170
SUGGEST: Process	0.124	0.020	6.32	0	0.086	0.163
APT-F: Challenge	0.135	0.023	5.99	0	0.091	0.179
DECLARE: Present	0.136	0.020	6.87	0	0.097	0.175
APT-C: Explain	0.137	0.019	7.26	0	0.100	0.173
SUGGEST: Approach	0.174	0.066	2.65	0.008	0.045	0.303
APT-C: Share Reasoning	0.190	0.017	11.23	0	0.157	0.224
Conversation 2						
DECLARE: Present	0.017	0.006	2.89	0.004	0.005	0.028
Conversation 3						
SUGGEST: Approach	0.041	0.011	3.81	0	0.020	0.063
Conversation 4						
APT-C: Share Reasoning	0.027	0.014	1.96	0.05	0.000	0.053
DECLARE: Activity	0.034	0.016	2.07	0.038	0.002	0.066
Design Cycle 1						
APT-C: Share Reasoning	0.011	0.003	3.44	0.001	0.005	0.017
DECLARE: Present	0.021	0.003	6.18	0	0.015	0.028
Design Cycle 2						
SUGGEST: Approach	0.036	0.010	3.81	0	0.018	0.055
Sample of Conversations						
ELICIT: Pose	-0.022	0.010	-2.11	0.035	-0.042	-0.002
DECLARE: POV	-0.021	0.009	-2.49	0.013	-0.038	-0.005
SUGGEST: Approach	0.018	0.006	2.95	0.003	0.006	0.031
DECLARE: Present	0.019	0.003	5.85	0	0.012	0.025
Knowledge of Data						
Conversation 1						
APT-C: Explain	0.042	0.018	2.31	0.021	0.006	0.078
SUGGEST: Role	0.047	0.023	2.01	0.045	0.001	0.092
APT-C: Share Reasoning	0.047	0.016	2.97	0.003	0.016	0.079
ELICIT: Pose	0.054	0.019	2.93	0.003	0.018	0.091
APT-F: Challenge	0.056	0.020	2.77	0.006	0.016	0.096
ELICIT: Process	0.058	0.020	2.83	0.005	0.018	0.098
APT-C: Say More	0.072	0.019	3.76	0	0.034	0.109

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ADMIN: Pose	0.074	0.016	4.53	0	0.042	0.105
ADMIN: State	0.077	0.016	4.73	0	0.045	0.109
SUGGEST: Process	0.081	0.015	5.36	0	0.051	0.110
DECLARE: Activity	0.081	0.016	4.93	0	0.049	0.114
DECLARE: Inform	0.094	0.016	6.07	0	0.064	0.125
ELICIT: Clarify	0.099	0.016	6.32	0	0.068	0.130
DECLARE: Present	0.102	0.015	6.78	0	0.072	0.131
Conversation 2						
ELICIT: Pose	-0.066	0.029	-2.25	0.024	-0.123	-0.009
SUGGEST: Process	-0.064	0.029	-2.19	0.028	-0.121	-0.007
DECLARE: Inform	0.021	0.008	2.5	0.012	0.005	0.038
Conversation 3						
DECLARE: POV	-0.072	0.037	-1.98	0.048	-0.144	-0.001
SUGGEST: Response	-0.048	0.023	-2.05	0.04	-0.094	-0.002
SUGGEST: Approach	0.071	0.021	3.38	0.001	0.030	0.112
Conversation 4						
APT-C: Explain	0.062	0.024	2.55	0.011	0.014	0.109
APT-C: Share Reasoning	0.079	0.027	2.87	0.004	0.025	0.132
ELICIT: Clarify	0.090	0.023	3.95	0	0.045	0.134
DECLARE: Activity	0.101	0.034	3.01	0.003	0.035	0.167
DECLARE: Inform	0.102	0.019	5.4	0	0.065	0.139
SUGGEST: Process	0.104	0.031	3.32	0.001	0.043	0.166
ADMIN: Pose	0.121	0.023	5.25	0	0.076	0.166
APT-C: Restate	0.134	0.026	5.2	0	0.084	0.185
ADMIN: State	0.155	0.020	7.76	0	0.116	0.194
Design Cycle 1						
DECLARE: POV	-0.050	0.019	-2.6	0.009	-0.087	-0.012
ADMIN: Pose	0.023	0.007	3.14	0.002	0.009	0.037
ELICIT: Clarify	0.027	0.007	3.83	0	0.013	0.041
DECLARE: Inform	0.038	0.006	6.48	0	0.026	0.049
DECLARE: Present	0.042	0.006	6.88	0	0.030	0.054
Design Cycle 2						
DECLARE: Activity	-0.097	0.033	-2.96	0.003	-0.161	-0.033
ELICIT: Clarify	0.052	0.023	2.31	0.021	0.008	0.097
DECLARE: POV	0.064	0.027	2.35	0.019	0.011	0.116
APT-C: Explain	0.064	0.029	2.21	0.027	0.007	0.122
ADMIN: State	0.093	0.028	3.36	0.001	0.039	0.147
APT-F: Challenge	0.105	0.042	2.51	0.012	0.023	0.187
SUGGEST: Role	0.110	0.052	2.11	0.035	0.008	0.212
APT-C: Restate	0.121	0.033	3.72	0	0.057	0.185
SUGGEST: Response	0.132	0.027	4.96	0	0.080	0.184
ADMIN: Pose	0.154	0.025	6.12	0	0.105	0.204
ADMIN: Action	0.155	0.041	3.81	0	0.075	0.235
DECLARE: Present	0.184	0.025	7.28	0	0.134	0.233
APT-C: Share Reasoning	0.204	0.028	7.26	0	0.149	0.259
APT-F: Restate	0.219	0.076	2.89	0.004	0.070	0.367
ELICIT: Pose	0.241	0.029	8.41	0	0.185	0.297
SUGGEST: Process	0.279	0.023	12.19	0	0.234	0.324
ELICIT: Process	0.300	0.029	10.46	0	0.244	0.356
SUGGEST: Approach	0.318	0.053	6.02	0	0.215	0.422

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
Skill of Data						
Conversation 1						
APT-F: Challenge	0.034	0.014	2.42	0.016	0.006	0.062
ELICIT: Process	0.035	0.014	2.48	0.013	0.007	0.063
ADMIN: State	0.040	0.012	3.36	0.001	0.017	0.063
ADMIN: Pose	0.041	0.011	3.65	0	0.019	0.063
APT-C: Say More	0.046	0.013	3.52	0	0.020	0.071
DECLARE: Activity	0.050	0.011	4.54	0	0.028	0.072
SUGGEST: Process	0.051	0.010	5.35	0	0.032	0.070
DECLARE: Inform	0.053	0.010	5.06	0	0.032	0.073
ELICIT: Clarify	0.054	0.011	4.98	0	0.033	0.075
DECLARE: Present	0.065	0.010	6.85	0	0.047	0.084
Conversation 3						
SUGGEST: Response	-0.045	0.023	-1.96	0.05	-0.091	0.000
DECLARE: Inform	-0.020	0.009	-2.18	0.03	-0.038	-0.002
SUGGEST: Approach	0.059	0.014	4.3	0	0.032	0.086
Conversation 4						
ADMIN: State	0.048	0.012	3.93	0	0.024	0.071
SUGGEST: Process	0.050	0.017	2.94	0.003	0.017	0.084
Design Cycle 1						
DECLARE: POV	-0.048	0.020	-2.4	0.017	-0.087	-0.009
ELICIT: Pose	-0.041	0.020	-2.07	0.038	-0.080	-0.002
DECLARE: Inform	0.017	0.005	3.06	0.002	0.006	0.027
DECLARE: Present	0.031	0.005	6.44	0	0.022	0.040
Design Cycle 2						
DECLARE: POV	-0.080	0.034	-2.33	0.02	-0.147	-0.013
ADMIN: State	0.030	0.008	3.61	0	0.014	0.046
SUGGEST: Approach	0.057	0.013	4.47	0	0.032	0.083
Sample of Conversations						
DECLARE: POV	-0.063	0.018	-3.4	0.001	-0.099	-0.026
ELICIT: Pose	-0.043	0.015	-2.85	0.004	-0.072	-0.013
SUGGEST: Response	-0.023	0.011	-2.16	0.031	-0.044	-0.002
SUGGEST: Process	0.012	0.005	2.35	0.019	0.002	0.022
ADMIN: Pose	0.013	0.006	2.32	0.02	0.002	0.024
ADMIN: State	0.016	0.005	3.01	0.003	0.006	0.027
DECLARE: Present	0.028	0.005	6.02	0	0.019	0.037
SUGGEST: Approach	0.035	0.008	4.15	0	0.018	0.051
Identity as Engineer						
Conversation 2						
DECLARE: Activity	0.020	0.007	2.98	0.003	0.007	0.033
SUGGEST: Process	0.021	0.006	3.81	0	0.010	0.032
Conversation 3						
ADMIN: Pose	0.029	0.012	2.44	0.015	0.006	0.053
DECLARE: Activity	0.032	0.010	3.21	0.001	0.013	0.052
APT-C: Share Reasoning	0.038	0.014	2.73	0.006	0.011	0.065
DECLARE: Present	0.043	0.009	4.51	0	0.024	0.061
SUGGEST: Approach	0.082	0.016	5.07	0	0.050	0.114
Conversation 4						
SUGGEST: Response	0.032	0.014	2.25	0.025	0.004	0.060
ADMIN: State	0.043	0.010	4.39	0	0.024	0.062

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ADMIN: Action	0.043	0.018	2.47	0.013	0.009	0.078
DECLARE: Activity	0.044	0.013	3.28	0.001	0.018	0.070
SUGGEST: Process	0.046	0.012	3.66	0	0.021	0.070
Design Cycle 1						
DECLARE: Activity	0.015	0.006	2.55	0.011	0.003	0.026
ADMIN: Pose	0.020	0.005	3.78	0	0.009	0.030
SUGGEST: Process	0.020	0.005	4.22	0	0.011	0.029
Design Cycle 2						
SUGGEST: Process	0.020	0.010	2.1	0.036	0.001	0.039
APT-C: Share Reasoning	0.023	0.011	2.09	0.037	0.001	0.045
ADMIN: Pose	0.024	0.010	2.46	0.014	0.005	0.042
ADMIN: State	0.033	0.009	3.68	0	0.016	0.051
DECLARE: Activity	0.036	0.008	4.49	0	0.020	0.052
DECLARE: Present	0.044	0.008	5.49	0	0.028	0.060
SUGGEST: Approach	0.065	0.013	5.05	0	0.040	0.090
Sample of Conversations						
DECLARE: POV	-0.021	0.010	-1.99	0.047	-0.041	0.000
ELICIT: Process	0.015	0.007	2.15	0.032	0.001	0.029
ADMIN: State	0.023	0.006	4.1	0	0.012	0.035
SUGGEST: Process	0.025	0.005	4.85	0	0.015	0.035
ADMIN: Pose	0.026	0.005	4.71	0	0.015	0.036
DECLARE: Present	0.028	0.005	5.1	0	0.017	0.038
DECLARE: Activity	0.029	0.005	5.42	0	0.018	0.039
SUGGEST: Approach	0.037	0.008	4.36	0	0.020	0.053
Identity of Intern						
Conversation 4						
APT-C: Share Reasoning	0.008	0.004	1.99	0.047	0.000	0.016
Design Cycle 1						
DECLARE: Present	0.005	0.002	3.28	0.001	0.002	0.008
Design Cycle 2						
APT-C: Share Reasoning	0.004	0.002	2.47	0.014	0.001	0.008
SUGGEST: Approach	0.005	0.002	2.04	0.041	0.000	0.009
Sample of Conversations						
APT-C: Share Reasoning	0.002	0.001	2.35	0.019	0.000	0.005
Skill of Collaboration						
Conversation 2						
ADMIN: State	0.019	0.007	2.73	0.006	0.005	0.033
APT-C: Share Reasoning	0.022	0.006	3.87	0	0.011	0.033
SUGGEST: Process	0.022	0.006	3.81	0	0.011	0.034
ADMIN: Pose	0.025	0.007	3.89	0	0.013	0.038
ADMIN: Action	0.028	0.007	4.24	0	0.015	0.042
Conversation 3						
SUGGEST: Process	0.041	0.015	2.77	0.006	0.012	0.070
DECLARE: Inform	0.044	0.011	4.21	0	0.024	0.065
ADMIN: State	0.054	0.018	3	0.003	0.019	0.089
ADMIN: Pose	0.059	0.015	3.85	0	0.029	0.089
DECLARE: Activity	0.067	0.013	5.25	0	0.042	0.092
DECLARE: Present	0.069	0.013	5.32	0	0.044	0.095
SUGGEST: Approach	0.076	0.028	2.75	0.006	0.022	0.130

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
APT-C: Share Reasoning	0.083	0.017	4.89	0	0.050	0.116
Conversation 4						
DECLARE: Inform	0.028	0.010	2.71	0.007	0.008	0.048
ADMIN: State	0.038	0.012	3.14	0.002	0.014	0.061
SUGGEST: Process	0.054	0.015	3.68	0	0.025	0.083
DECLARE: Present	0.081	0.019	4.28	0	0.044	0.119
Design Cycle 1						
APT-C: Share Reasoning	0.015	0.004	3.35	0.001	0.006	0.023
ELICIT: Process	0.020	0.005	3.69	0	0.009	0.030
ADMIN: State	0.022	0.005	4.62	0	0.013	0.032
SUGGEST: Process	0.025	0.004	5.87	0	0.016	0.033
ADMIN: Action	0.028	0.005	5.46	0	0.018	0.037
ADMIN: Pose	0.030	0.004	6.82	0	0.021	0.039
Design Cycle 2						
ADMIN: Pose	0.041	0.012	3.33	0.001	0.017	0.065
DECLARE: Inform	0.042	0.008	5.28	0	0.026	0.057
SUGGEST: Process	0.050	0.011	4.49	0	0.028	0.071
ADMIN: State	0.050	0.012	4.21	0	0.027	0.073
SUGGEST: Approach	0.054	0.023	2.39	0.017	0.010	0.098
APT-C: Share Reasoning	0.054	0.013	4.28	0	0.029	0.079
DECLARE: Activity	0.062	0.010	6.11	0	0.042	0.082
DECLARE: Present	0.072	0.010	6.93	0	0.051	0.092
Sample of Conversations						
SUGGEST: Response	0.022	0.008	2.73	0.006	0.006	0.038
ELICIT: Clarify	0.027	0.007	4.01	0	0.014	0.040
ELICIT: Process	0.028	0.008	3.5	0	0.012	0.044
APT-C: Share Reasoning	0.031	0.006	5.13	0	0.019	0.043
SUGGEST: Approach	0.036	0.013	2.82	0.005	0.011	0.061
ADMIN: Action	0.038	0.008	4.64	0	0.022	0.054
DECLARE: Inform	0.042	0.005	8.54	0	0.032	0.052
ADMIN: State	0.044	0.006	7.12	0	0.032	0.056
SUGGEST: Process	0.044	0.006	7.97	0	0.033	0.055
DECLARE: Activity	0.047	0.006	7.89	0	0.035	0.058
DECLARE: Present	0.047	0.006	7.93	0	0.036	0.059
ADMIN: Pose	0.048	0.006	8.28	0	0.037	0.060
Skill of Professionalism						
Conversation 1						
ADMIN: State	0.067	0.011	5.89	0	0.044	0.089
APT-F: Press Reasoning	0.072	0.014	5.21	0	0.045	0.100
ELICIT: Process	0.072	0.012	6.13	0	0.049	0.096
SUGGEST: Process	0.075	0.010	7.64	0	0.056	0.094
ADMIN: Pose	0.079	0.010	7.63	0	0.059	0.099
SUGGEST: Role	0.087	0.011	7.91	0	0.066	0.109
ADMIN: Action	0.095	0.011	8.42	0	0.073	0.118
Conversation 2						
DECLARE: Activity	0.064	0.012	5.47	0	0.041	0.086
ADMIN: State	0.071	0.011	6.51	0	0.049	0.092
SUGGEST: Process	0.073	0.010	7.24	0	0.053	0.093
SUGGEST: Role	0.075	0.012	6.4	0	0.052	0.098
ELICIT: Process	0.075	0.011	7.05	0	0.055	0.096

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ADMIN: Pose	0.080	0.011	7.56	0	0.060	0.101
ADMIN: Action	0.103	0.011	9.71	0	0.082	0.123
Conversation 3						
APT-C: Share Reasoning	0.042	0.015	2.74	0.006	0.012	0.072
ELICIT: Process	0.056	0.011	4.9	0	0.033	0.078
SUGGEST: Approach	0.058	0.019	3.1	0.002	0.021	0.094
APT-C: Add More	0.059	0.025	2.37	0.018	0.010	0.108
SUGGEST: Process	0.072	0.010	7.45	0	0.053	0.091
ADMIN: State	0.075	0.011	6.92	0	0.053	0.096
ADMIN: Pose	0.079	0.010	7.9	0	0.059	0.098
ADMIN: Action	0.085	0.011	7.56	0	0.063	0.108
SUGGEST: Role	0.090	0.012	7.67	0	0.067	0.114
Conversation 4						
ADMIN: Pose	0.026	0.011	2.51	0.012	0.006	0.047
ADMIN: State	0.038	0.009	4.09	0	0.020	0.055
SUGGEST: Process	0.041	0.011	3.79	0	0.020	0.062
DECLARE: Activity	0.043	0.011	3.92	0	0.022	0.065
ADMIN: Action	0.054	0.012	4.51	0	0.031	0.077
SUGGEST: Role	0.066	0.020	3.33	0.001	0.027	0.105
Design Cycle 1						
DECLARE: Activity	0.050	0.010	5.28	0	0.032	0.069
APT-F: Press Reasoning	0.063	0.012	5.29	0	0.039	0.086
ADMIN: State	0.069	0.008	8.8	0	0.054	0.084
ELICIT: Process	0.074	0.008	9.4	0	0.059	0.090
SUGGEST: Process	0.075	0.007	10.5	0	0.061	0.088
ADMIN: Pose	0.080	0.007	10.74	0	0.066	0.095
SUGGEST: Role	0.082	0.008	10.21	0	0.066	0.098
ADMIN: Action	0.100	0.008	13.1	0	0.085	0.115
Design Cycle 2						
APT-C: Restate	0.029	0.013	2.2	0.028	0.003	0.054
DECLARE: Activity	0.034	0.009	3.58	0	0.015	0.052
SUGGEST: Approach	0.044	0.016	2.82	0.005	0.014	0.075
ELICIT: Process	0.047	0.009	5.04	0	0.029	0.065
ADMIN: State	0.062	0.008	7.88	0	0.046	0.077
ADMIN: Pose	0.063	0.008	8.31	0	0.048	0.078
SUGGEST: Process	0.064	0.008	8.49	0	0.049	0.079
ADMIN: Action	0.078	0.009	8.95	0	0.061	0.095
SUGGEST: Role	0.081	0.010	8.49	0	0.062	0.100
Sample of Conversations						
DECLARE: Activity	0.041	0.007	6.06	0	0.027	0.054
APT-F: Press Reasoning	0.054	0.010	5.17	0	0.033	0.074
ELICIT: Process	0.062	0.006	10.61	0	0.051	0.073
ADMIN: State	0.065	0.005	11.83	0	0.054	0.075
SUGGEST: Process	0.068	0.005	13.48	0	0.059	0.078
ADMIN: Pose	0.071	0.005	13.55	0	0.061	0.082
SUGGEST: Role	0.079	0.006	13.15	0	0.067	0.090
ADMIN: Action	0.090	0.006	15.95	0	0.079	0.101

Table H3

*AME results for epistemic elements with a **high** frequency of evidence in* Nephrotex *discourse.*

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
Epistemology of Design						
Conversation 2						
APT-C: Restate	-0.106	0.048	-2.18	0.029	-0.201	-0.011
ADMIN: Pose	-0.077	0.038	-2.03	0.043	-0.151	-0.003
DECLARE: Present	0.062	0.022	2.79	0.005	0.019	0.106
SUGGEST: Process	0.075	0.015	5.08	0	0.046	0.104
SUGGEST: Approach	0.096	0.026	3.64	0	0.044	0.147
APT-C: Share Reasoning	0.121	0.012	9.83	0	0.097	0.145
Conversation 3						
DECLARE: Activity	-0.121	0.036	-3.33	0.001	-0.192	-0.050
DECLARE: POV	-0.095	0.044	-2.15	0.032	-0.182	-0.008
APT-C: Share Reasoning	0.094	0.021	4.55	0	0.053	0.134
DECLARE: Present	0.099	0.014	6.95	0	0.071	0.127
SUGGEST: Process	0.133	0.013	10.28	0	0.108	0.159
SUGGEST: Approach	0.133	0.031	4.24	0	0.072	0.195
Conversation 4						
DECLARE: POV	0.087	0.022	4.02	0	0.045	0.130
SUGGEST: Process	0.123	0.033	3.78	0	0.059	0.187
ELICIT: Process	0.125	0.055	2.27	0.023	0.017	0.233
SUGGEST: Approach	0.146	0.051	2.89	0.004	0.047	0.246
ELICIT: Pose	0.173	0.024	7.35	0	0.127	0.219
APT-C: Share Reasoning	0.180	0.022	8.35	0	0.138	0.222
APT-F: Restate	0.205	0.056	3.66	0	0.095	0.315
Design Cycle 1						
ADMIN: State	0.058	0.013	4.3	0	0.031	0.084
APT-C: Explain	0.064	0.011	5.65	0	0.042	0.087
DECLARE: Present	0.071	0.013	5.47	0	0.045	0.096
SUGGEST: Process	0.075	0.010	7.23	0	0.055	0.096
SUGGEST: Approach	0.114	0.022	5.2	0	0.071	0.156
APT-C: Share Reasoning	0.132	0.008	16.84	0	0.116	0.147
Design Cycle 2						
DECLARE: Activity	-0.111	0.031	-3.58	0	-0.173	-0.050
ELICIT: Clarify	-0.050	0.019	-2.58	0.01	-0.088	-0.012
DECLARE: Inform	-0.035	0.013	-2.64	0.008	-0.062	-0.009
ELICIT: Process	0.056	0.019	3	0.003	0.020	0.093
ELICIT: Pose	0.071	0.018	4	0	0.036	0.106

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
DECLARE: Present	0.087	0.015	6.01	0	0.059	0.116
APT-F: Restate	0.098	0.042	2.33	0.02	0.016	0.181
APT-C: Share Reasoning	0.123	0.015	8.27	0	0.094	0.152
SUGGEST: Process	0.126	0.013	10.06	0	0.101	0.150
SUGGEST: Approach	0.129	0.027	4.71	0	0.075	0.182
Sample of Conversations						
ADMIN: Action	-0.082	0.029	-2.86	0.004	-0.139	-0.026
DECLARE: Activity	-0.062	0.018	-3.37	0.001	-0.099	-0.026
ELICIT: Clarify	-0.028	0.014	-2.02	0.043	-0.055	-0.001
ADMIN: State	0.028	0.012	2.4	0.016	0.005	0.051
ELICIT: Process	0.036	0.013	2.89	0.004	0.012	0.061
APT-C: Explain	0.038	0.011	3.57	0	0.017	0.058
APT-F: Restate	0.075	0.029	2.56	0.01	0.018	0.132
DECLARE: Present	0.078	0.010	8.18	0	0.060	0.097
SUGGEST: Process	0.095	0.008	11.86	0	0.079	0.110
SUGGEST: Approach	0.119	0.017	6.94	0	0.085	0.153
APT-C: Share Reasoning	0.126	0.007	17.67	0	0.112	0.140
Knowledge of Design						
Conversation 1						
APT-C: Restate	0.136	0.046	2.95	0.003	0.046	0.226
APT-F: Press Reasoning	0.136	0.053	2.54	0.011	0.031	0.241
SUGGEST: Response	0.141	0.046	3.07	0.002	0.051	0.232
ELICIT: Clarify	0.143	0.040	3.56	0	0.065	0.222
DECLARE: Inform	0.148	0.037	3.96	0	0.075	0.222
ELICIT: Process	0.152	0.042	3.66	0	0.070	0.233
DECLARE: POV	0.162	0.028	5.9	0	0.108	0.216
APT-F: Say More	0.180	0.054	3.31	0.001	0.074	0.287
ELICIT: Pose	0.183	0.034	5.45	0	0.117	0.249
APT-F: Revoice	0.191	0.071	2.71	0.007	0.053	0.329
APT-C: Add More	0.209	0.038	5.44	0	0.134	0.285
APT-C: Say More	0.238	0.037	6.35	0	0.164	0.311
DECLARE: Present	0.241	0.029	8.26	0	0.183	0.298
SUGGEST: Process	0.260	0.027	9.66	0	0.208	0.313
APT-C: Explain	0.261	0.026	9.88	0	0.209	0.313
ADMIN: Pose	0.305	0.028	10.97	0	0.251	0.360
APT-F: Challenge	0.309	0.031	9.96	0	0.249	0.370
ADMIN: State	0.323	0.028	11.37	0	0.267	0.378
APT-C: Share Reasoning	0.354	0.022	15.82	0	0.310	0.398
Conversation 2						
APT-C: Add More	-0.150	0.069	-2.18	0.029	-0.284	-0.015

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
APT-C: Explain	0.078	0.032	2.45	0.014	0.016	0.140
ADMIN: Action	0.134	0.035	3.81	0	0.065	0.203
ELICIT: Process	0.140	0.031	4.56	0	0.080	0.200
APT-C: Share Reasoning	0.165	0.024	7.02	0	0.119	0.211
DECLARE: Present	0.175	0.036	4.85	0	0.104	0.246
SUGGEST: Process	0.183	0.025	7.42	0	0.135	0.231
ADMIN: Pose	0.188	0.031	6.15	0	0.128	0.248
ADMIN: State	0.192	0.029	6.62	0	0.135	0.249
SUGGEST: Approach	0.222	0.047	4.69	0	0.129	0.315
Conversation 3						
DECLARE: Activity	-0.089	0.035	-2.59	0.01	-0.157	-0.022
ELICIT: Clarify	0.057	0.026	2.18	0.029	0.006	0.108
ADMIN: State	0.112	0.036	3.14	0.002	0.042	0.182
SUGGEST: Role	0.119	0.051	2.31	0.021	0.018	0.219
SUGGEST: Response	0.121	0.029	4.17	0	0.064	0.178
APT-C: Share Reasoning	0.136	0.038	3.59	0	0.062	0.211
DECLARE: Present	0.180	0.025	7.11	0	0.130	0.230
ADMIN: Pose	0.199	0.029	6.89	0	0.142	0.256
ADMIN: Action	0.205	0.043	4.78	0	0.121	0.290
ELICIT: Pose	0.215	0.036	6	0	0.145	0.285
SUGGEST: Process	0.293	0.024	12.38	0	0.247	0.340
ELICIT: Process	0.312	0.029	10.89	0	0.256	0.368
SUGGEST: Approach	0.366	0.063	5.84	0	0.243	0.489
Conversation 4						
APT-F: Challenge	0.107	0.051	2.08	0.038	0.006	0.207
DECLARE: POV	0.127	0.035	3.67	0	0.059	0.195
SUGGEST: Response	0.164	0.056	2.94	0.003	0.055	0.274
SUGGEST: Process	0.176	0.058	3.04	0.002	0.063	0.289
APT-C: Restate	0.198	0.052	3.81	0	0.096	0.299
ELICIT: Pose	0.248	0.045	5.47	0	0.159	0.336
APT-C: Share Reasoning	0.252	0.042	6.06	0	0.170	0.333
DECLARE: Present	0.327	0.105	3.11	0.002	0.121	0.533
APT-F: Restate	0.364	0.124	2.93	0.003	0.120	0.608
Design Cycle 1						
ELICIT: Pose	0.054	0.021	2.58	0.01	0.013	0.095
SUGGEST: Response	0.062	0.024	2.6	0.009	0.015	0.109
APT-C: Say More	0.080	0.031	2.6	0.009	0.020	0.141
ADMIN: Action	0.084	0.028	3.04	0.002	0.030	0.138
APT-F: Challenge	0.106	0.028	3.82	0	0.052	0.160
APT-C: Explain	0.117	0.019	6.18	0	0.080	0.154

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ELICIT: Process	0.117	0.023	5.11	0	0.072	0.162
DECLARE: Present	0.136	0.021	6.32	0	0.094	0.178
SUGGEST: Process	0.171	0.017	10.16	0	0.138	0.204
ADMIN: Pose	0.195	0.019	10.04	0	0.157	0.233
ADMIN: State	0.211	0.019	10.96	0	0.173	0.249
APT-C: Share Reasoning	0.218	0.014	15.53	0	0.190	0.245
SUGGEST: Approach	0.248	0.040	6.2	0	0.170	0.327
Sample of Conversations						
APT-F: Press Reasoning	-0.117	0.057	-2.06	0.039	-0.228	-0.006
DECLARE: Inform	0.042	0.014	3.03	0.002	0.015	0.068
ELICIT: Clarify	0.062	0.017	3.73	0	0.030	0.095
APT-C: Restate	0.089	0.021	4.13	0	0.047	0.131
APT-C: Explain	0.103	0.017	6.19	0	0.071	0.136
SUGGEST: Response	0.106	0.018	5.98	0	0.072	0.141
APT-F: Challenge	0.110	0.024	4.56	0	0.062	0.157
ADMIN: Action	0.110	0.024	4.69	0	0.064	0.156
ELICIT: Pose	0.121	0.017	7.14	0	0.088	0.154
APT-F: Restate	0.166	0.050	3.3	0.001	0.068	0.265
DECLARE: Present	0.170	0.017	10.22	0	0.137	0.202
ADMIN: State	0.174	0.016	10.54	0	0.142	0.206
ADMIN: Pose	0.189	0.016	11.86	0	0.158	0.220
ELICIT: Process	0.201	0.018	11.31	0	0.166	0.236
APT-C: Share Reasoning	0.218	0.014	16.17	0	0.192	0.245
SUGGEST: Process	0.221	0.014	15.83	0	0.193	0.248
SUGGEST: Approach	0.290	0.033	8.89	0	0.226	0.353
Skill of Design						
Conversation 1						
SUGGEST: Response	0.073	0.037	1.97	0.049	0.000	0.146
DECLARE: POV	0.074	0.021	3.47	0.001	0.032	0.116
ELICIT: Process	0.080	0.033	2.38	0.017	0.014	0.145
ELICIT: Pose	0.084	0.028	3.02	0.003	0.030	0.138
APT-F: Press Reasoning	0.089	0.040	2.22	0.026	0.010	0.168
APT-C: Say More	0.099	0.034	2.94	0.003	0.033	0.165
APT-F: Revoice	0.115	0.056	2.03	0.042	0.004	0.225
APT-C: Explain	0.147	0.020	7.45	0	0.108	0.186
DECLARE: Present	0.149	0.021	6.94	0	0.107	0.191
APT-F: Challenge	0.157	0.025	6.2	0	0.107	0.206
SUGGEST: Process	0.185	0.019	9.88	0	0.149	0.222
APT-C: Share Reasoning	0.186	0.017	11.18	0	0.154	0.219
ADMIN: Pose	0.189	0.020	9.2	0	0.148	0.229

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ADMIN: State	0.201	0.021	9.63	0	0.160	0.242
Conversation 2						
DECLARE: POV	-0.189	0.045	-4.16	0	-0.278	-0.100
APT-F: Challenge	-0.148	0.068	-2.19	0.028	-0.281	-0.016
DECLARE: Inform	-0.081	0.033	-2.48	0.013	-0.146	-0.017
ADMIN: Action	0.082	0.029	2.84	0.004	0.026	0.139
ADMIN: State	0.085	0.025	3.37	0.001	0.035	0.134
DECLARE: Present	0.089	0.030	2.95	0.003	0.030	0.148
ADMIN: Pose	0.091	0.026	3.49	0	0.040	0.142
SUGGEST: Process	0.115	0.021	5.55	0	0.075	0.156
APT-C: Share Reasoning	0.125	0.020	6.38	0	0.086	0.163
SUGGEST: Approach	0.136	0.037	3.68	0	0.064	0.208
Conversation 3						
DECLARE: POV	-0.103	0.047	-2.17	0.03	-0.196	-0.010
DECLARE: Activity	-0.066	0.030	-2.19	0.028	-0.126	-0.007
DECLARE: Present	0.086	0.021	4.11	0	0.045	0.128
ELICIT: Pose	0.090	0.030	3.01	0.003	0.031	0.149
APT-C: Share Reasoning	0.104	0.029	3.57	0	0.047	0.162
SUGGEST: Role	0.107	0.039	2.76	0.006	0.031	0.183
ADMIN: Pose	0.118	0.023	5.18	0	0.073	0.163
ADMIN: Action	0.132	0.033	4.01	0	0.068	0.197
ELICIT: Process	0.173	0.021	8.08	0	0.131	0.215
SUGGEST: Process	0.195	0.017	11.17	0	0.161	0.229
SUGGEST: Approach	0.273	0.042	6.5	0	0.191	0.355
Conversation 4						
ELICIT: Pose	0.097	0.035	2.8	0.005	0.029	0.166
SUGGEST: Response	0.134	0.039	3.43	0.001	0.057	0.210
APT-C: Share Reasoning	0.138	0.030	4.63	0	0.079	0.196
APT-C: Restate	0.139	0.036	3.82	0	0.068	0.210
DECLARE: Present	0.150	0.070	2.15	0.031	0.013	0.287
SUGGEST: Approach	0.162	0.065	2.49	0.013	0.035	0.289
ELICIT: Process	0.172	0.066	2.62	0.009	0.043	0.301
APT-F: Revoice	0.177	0.067	2.65	0.008	0.046	0.309
SUGGEST: Process	0.191	0.037	5.1	0	0.117	0.264
Design Cycle 1						
DECLARE: POV	-0.051	0.020	-2.55	0.011	-0.090	-0.012
ELICIT: Process	0.056	0.020	2.8	0.005	0.017	0.096
ADMIN: Action	0.067	0.022	3.03	0.002	0.024	0.110
APT-C: Explain	0.078	0.016	5.01	0	0.047	0.108
DECLARE: Present	0.096	0.017	5.55	0	0.062	0.130

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ADMIN: Pose	0.129	0.016	8.25	0	0.098	0.159
ADMIN: State	0.134	0.015	8.66	0	0.104	0.165
SUGGEST: Process	0.139	0.013	10.78	0	0.114	0.165
APT-C: Share Reasoning	0.139	0.011	12.21	0	0.117	0.162
SUGGEST: Approach	0.171	0.030	5.63	0	0.111	0.230
Design Cycle 2						
DECLARE: Activity	-0.073	0.029	-2.56	0.011	-0.129	-0.017
DECLARE: Inform	-0.040	0.018	-2.26	0.024	-0.075	-0.005
SUGGEST: Response	0.060	0.023	2.64	0.008	0.015	0.104
ADMIN: Pose	0.064	0.022	2.95	0.003	0.022	0.107
DECLARE: Present	0.077	0.022	3.53	0	0.034	0.119
ELICIT: Pose	0.081	0.025	3.3	0.001	0.033	0.129
SUGGEST: Role	0.095	0.039	2.46	0.014	0.019	0.170
ADMIN: Action	0.100	0.031	3.2	0.001	0.039	0.162
APT-C: Share Reasoning	0.108	0.023	4.76	0	0.064	0.153
APT-F: Revoice	0.138	0.053	2.61	0.009	0.035	0.242
ELICIT: Process	0.159	0.022	7.21	0	0.116	0.203
SUGGEST: Process	0.181	0.018	9.94	0	0.145	0.216
SUGGEST: Approach	0.224	0.036	6.21	0	0.153	0.295
Sample of Conversations						
DECLARE: POV	-0.048	0.017	-2.86	0.004	-0.080	-0.015
SUGGEST: Response	0.045	0.016	2.87	0.004	0.014	0.075
APT-C: Explain	0.057	0.014	4.01	0	0.029	0.085
APT-F: Revoice	0.073	0.036	2.01	0.044	0.002	0.145
ADMIN: Action	0.076	0.019	4.03	0	0.039	0.113
ADMIN: State	0.077	0.014	5.33	0	0.049	0.105
DECLARE: Present	0.089	0.014	6.29	0	0.061	0.117
ADMIN: Pose	0.102	0.013	7.58	0	0.076	0.129
ELICIT: Process	0.105	0.015	7.07	0	0.076	0.135
APT-C: Share Reasoning	0.128	0.012	11.16	0	0.106	0.151
SUGGEST: Process	0.156	0.011	13.72	0	0.134	0.179
SUGGEST: Approach	0.198	0.023	8.44	0	0.152	0.244
Knowledge of Attribute						
Conversation 1						
ADMIN: Action	-0.294	0.123	-2.38	0.017	-0.535	-0.052
SUGGEST: Process	0.104	0.032	3.3	0.001	0.042	0.166
DECLARE: Activity	0.184	0.036	5.14	0	0.114	0.255
APT-F: Say More	0.236	0.053	4.45	0	0.132	0.340
ELICIT: Clarify	0.287	0.033	8.67	0	0.222	0.352
DECLARE: Inform	0.328	0.030	10.86	0	0.269	0.387

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
APT-C: Add More	0.337	0.036	9.3	0	0.266	0.408
APT-C: Say More	0.340	0.037	9.08	0	0.267	0.414
ELICIT: Pose	0.342	0.029	11.9	0	0.286	0.398
APT-F: Press Reasoning	0.380	0.043	8.81	0	0.295	0.464
APT-F: Challenge	0.404	0.033	12.1	0	0.338	0.469
APT-C: Explain	0.411	0.023	17.58	0	0.365	0.457
APT-F: Revoice	0.424	0.069	6.12	0	0.288	0.560
APT-C: Share Reasoning	0.473	0.019	24.26	0	0.435	0.511
SUGGEST: Response	0.503	0.039	12.74	0	0.426	0.581
DECLARE: POV	0.535	0.020	26.93	0	0.496	0.574
DECLARE: Present	0.553	0.028	19.42	0	0.497	0.608
APT-C: Restate	0.694	0.053	13.01	0	0.589	0.798
Conversation 2						
ADMIN: State	-0.304	0.108	-2.83	0.005	-0.515	-0.094
ELICIT: Process	-0.147	0.055	-2.69	0.007	-0.254	-0.040
DECLARE: Activity	-0.098	0.045	-2.16	0.03	-0.186	-0.009
SUGGEST: Process	-0.092	0.035	-2.6	0.009	-0.161	-0.022
ELICIT: Clarify	0.102	0.022	4.72	0	0.060	0.145
DECLARE: Inform	0.162	0.017	9.73	0	0.130	0.195
DECLARE: Present	0.169	0.023	7.51	0	0.125	0.214
APT-C: Explain	0.189	0.018	10.69	0	0.154	0.224
APT-F: Challenge	0.200	0.026	7.82	0	0.150	0.250
APT-C: Add More	0.210	0.025	8.46	0	0.161	0.259
APT-C: Share Reasoning	0.279	0.013	21.91	0	0.254	0.303
Conversation 3						
ADMIN: Pose	-0.499	0.149	-3.36	0.001	-0.790	-0.208
DECLARE: Activity	-0.455	0.106	-4.31	0	-0.662	-0.248
ELICIT: Process	-0.221	0.062	-3.54	0	-0.343	-0.099
ELICIT: Clarify	0.104	0.022	4.62	0	0.060	0.147
SUGGEST: Response	0.165	0.024	6.83	0	0.117	0.212
DECLARE: POV	0.177	0.028	6.23	0	0.121	0.232
APT-C: Restate	0.208	0.030	6.86	0	0.148	0.267
APT-C: Explain	0.233	0.034	6.76	0	0.165	0.300
DECLARE: Inform	0.290	0.014	20.99	0	0.263	0.317
APT-C: Share Reasoning	0.335	0.029	11.74	0	0.279	0.391
APT-F: Challenge	0.372	0.053	7.06	0	0.269	0.475
DECLARE: Present	0.464	0.021	22.63	0	0.424	0.505
Conversation 4						
ADMIN: Pose	-0.340	0.155	-2.2	0.028	-0.643	-0.037
DECLARE: POV	0.136	0.040	3.45	0.001	0.059	0.214

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ELICIT: Clarify	0.168	0.039	4.29	0	0.091	0.244
APT-F: Revoice	0.200	0.091	2.2	0.028	0.022	0.379
SUGGEST: Response	0.236	0.050	4.7	0	0.138	0.335
DECLARE: Inform	0.318	0.029	10.8	0	0.260	0.375
APT-C: Restate	0.325	0.044	7.34	0	0.238	0.412
APT-F: Challenge	0.381	0.041	9.26	0	0.300	0.462
APT-C: Explain	0.411	0.030	13.8	0	0.353	0.470
DECLARE: Present	0.440	0.080	5.46	0	0.282	0.597
APT-C: Add More	0.455	0.055	8.32	0	0.348	0.562
APT-C: Share Reasoning	0.497	0.036	13.76	0	0.426	0.568
Design Cycle 1						
ADMIN: Action	-0.416	0.113	-3.68	0	-0.638	-0.195
ADMIN: Pose	-0.178	0.046	-3.9	0	-0.268	-0.089
SUGGEST: Role	-0.099	0.045	-2.22	0.026	-0.187	-0.012
ELICIT: Process	-0.094	0.040	-2.38	0.017	-0.172	-0.017
ELICIT: Pose	0.143	0.020	7.16	0	0.104	0.182
APT-F: Say More	0.148	0.041	3.64	0	0.069	0.228
ELICIT: Clarify	0.189	0.022	8.64	0	0.146	0.232
APT-C: Say More	0.205	0.028	7.44	0	0.151	0.259
SUGGEST: Response	0.206	0.021	9.86	0	0.165	0.248
APT-F: Revoice	0.237	0.049	4.86	0	0.142	0.333
APT-F: Press Reasoning	0.240	0.033	7.3	0	0.175	0.304
DECLARE: Inform	0.247	0.019	13.3	0	0.210	0.283
APT-C: Restate	0.284	0.022	12.69	0	0.240	0.328
APT-C: Add More	0.300	0.025	12.11	0	0.252	0.349
DECLARE: POV	0.323	0.014	22.57	0	0.295	0.352
APT-C: Explain	0.330	0.016	20.06	0	0.297	0.362
APT-F: Challenge	0.333	0.024	14.13	0	0.287	0.380
DECLARE: Present	0.394	0.019	20.73	0	0.357	0.431
APT-C: Share Reasoning	0.415	0.013	31.68	0	0.390	0.441
Design Cycle 2						
ADMIN: Pose	-0.484	0.112	-4.33	0	-0.703	-0.265
DECLARE: Activity	-0.437	0.092	-4.76	0	-0.616	-0.257
ELICIT: Process	-0.221	0.062	-3.59	0	-0.342	-0.101
SUGGEST: Process	-0.065	0.033	-1.97	0.049	-0.130	0.000
APT-C: Say More	0.102	0.049	2.06	0.039	0.005	0.198
ELICIT: Clarify	0.107	0.021	4.99	0	0.065	0.149
DECLARE: POV	0.129	0.024	5.31	0	0.081	0.177
SUGGEST: Response	0.176	0.024	7.35	0	0.129	0.223
APT-C: Restate	0.237	0.027	8.84	0	0.184	0.290

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
APT-C: Add More	0.286	0.042	6.81	0	0.204	0.368
DECLARE: Inform	0.295	0.015	19.68	0	0.266	0.324
APT-C: Explain	0.316	0.022	14.16	0	0.273	0.360
APT-F: Challenge	0.342	0.032	10.62	0	0.279	0.405
APT-C: Share Reasoning	0.391	0.024	16.39	0	0.345	0.438
DECLARE: Present	0.487	0.023	21.49	0	0.443	0.532
Sample of Conversations						
ADMIN: Action	-0.470	0.110	-4.26	0	-0.686	-0.254
ADMIN: Pose	-0.260	0.041	-6.32	0	-0.341	-0.180
ADMIN: State	-0.171	0.033	-5.25	0	-0.235	-0.107
SUGGEST: Role	-0.146	0.043	-3.39	0.001	-0.231	-0.062
ELICIT: Process	-0.134	0.033	-4.1	0	-0.198	-0.070
DECLARE: Activity	-0.076	0.025	-3.07	0.002	-0.125	-0.028
DECLARE: Present	0.004	0.001	3.67	0	0.002	0.006
APT-F: Say More	0.098	0.035	2.83	0.005	0.030	0.167
ELICIT: Pose	0.109	0.017	6.49	0	0.076	0.142
ELICIT: Clarify	0.148	0.015	10.08	0	0.119	0.176
APT-C: Say More	0.176	0.024	7.48	0	0.130	0.223
APT-F: Revoice	0.193	0.039	4.97	0	0.117	0.270
SUGGEST: Response	0.195	0.015	12.67	0	0.165	0.225
APT-F: Press Reasoning	0.214	0.031	6.97	0	0.154	0.274
DECLARE: POV	0.258	0.012	21.09	0	0.234	0.282
APT-C: Restate	0.263	0.017	15.64	0	0.230	0.296
APT-C: Add More	0.290	0.021	13.79	0	0.249	0.331
DECLARE: Inform	0.291	0.010	28.08	0	0.271	0.311
APT-C: Explain	0.322	0.013	24.67	0	0.296	0.348
APT-F: Challenge	0.332	0.019	17.75	0	0.295	0.369
APT-C: Share Reasoning	0.401	0.012	34.69	0	0.378	0.424
DECLARE: Present	0.436	0.014	31.06	0	0.408	0.463
Knowledge of CNT						
Conversation 1						
DECLARE: Activity	0.046	0.018	2.53	0.011	0.010	0.082
APT-F: Challenge	0.051	0.018	2.77	0.006	0.015	0.087
APT-C: Explain	0.051	0.014	3.77	0	0.025	0.078
APT-C: Share Reasoning	0.054	0.012	4.51	0	0.030	0.077
ELICIT: Clarify	0.061	0.016	3.73	0	0.029	0.093
APT-C: Say More	0.068	0.017	3.88	0	0.033	0.102
APT-C: Add More	0.085	0.015	5.74	0	0.056	0.114
DECLARE: Inform	0.097	0.012	7.85	0	0.072	0.121
APT-F: Revoice	0.102	0.022	4.7	0	0.060	0.145

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
SUGGEST: Approach	0.114	0.042	2.71	0.007	0.032	0.197
DECLARE: Present	0.141	0.011	13.37	0	0.120	0.162
Conversation 2						
APT-C: Say More	0.103	0.035	2.96	0.003	0.035	0.172
APT-F: Press Reasoning	0.111	0.044	2.51	0.012	0.025	0.198
APT-F: Challenge	0.140	0.029	4.79	0	0.083	0.197
APT-F: Say More	0.143	0.040	3.63	0	0.066	0.221
ELICIT: Pose	0.148	0.018	8.12	0	0.112	0.184
DECLARE: POV	0.149	0.019	7.82	0	0.111	0.186
ELICIT: Clarify	0.151	0.021	7.24	0	0.110	0.192
APT-C: Explain	0.152	0.020	7.51	0	0.113	0.192
SUGGEST: Approach	0.155	0.030	5.23	0	0.097	0.213
DECLARE: Inform	0.161	0.018	8.74	0	0.125	0.197
APT-C: Add More	0.162	0.026	6.21	0	0.111	0.213
SUGGEST: Response	0.178	0.018	10.01	0	0.143	0.213
APT-C: Restate	0.207	0.019	10.81	0	0.169	0.245
APT-F: Revoice	0.226	0.036	6.2	0	0.155	0.298
APT-C: Share Reasoning	0.229	0.015	14.87	0	0.199	0.259
DECLARE: Present	0.238	0.019	12.53	0	0.201	0.275
Conversation 4						
APT-C: Add More	0.049	0.022	2.19	0.029	0.005	0.092
ELICIT: Clarify	0.049	0.013	3.79	0	0.023	0.074
DECLARE: Inform	0.057	0.011	5.34	0	0.036	0.078
SUGGEST: Approach	0.061	0.027	2.22	0.026	0.007	0.114
Design Cycle 1						
DECLARE: Activity	0.067	0.020	3.43	0.001	0.029	0.105
APT-F: Press Reasoning	0.069	0.030	2.29	0.022	0.010	0.129
DECLARE: POV	0.088	0.014	6.51	0	0.062	0.115
APT-F: Say More	0.094	0.028	3.41	0.001	0.040	0.149
APT-C: Say More	0.100	0.020	5.04	0	0.061	0.139
APT-F: Challenge	0.103	0.019	5.52	0	0.066	0.139
APT-C: Explain	0.110	0.014	8.04	0	0.083	0.137
ELICIT: Pose	0.115	0.013	8.53	0	0.089	0.142
ELICIT: Clarify	0.120	0.015	8.2	0	0.091	0.149
APT-C: Add More	0.139	0.016	8.6	0	0.107	0.170
SUGGEST: Response	0.140	0.014	10.34	0	0.113	0.166
SUGGEST: Approach	0.145	0.022	6.45	0	0.101	0.189
DECLARE: Inform	0.147	0.013	11.6	0	0.122	0.171
APT-C: Restate	0.152	0.014	10.7	0	0.124	0.180
APT-C: Share Reasoning	0.154	0.011	13.79	0	0.132	0.176

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
APT-F: Revoice	0.178	0.022	7.92	0	0.134	0.222
DECLARE: Present	0.210	0.012	17.9	0	0.187	0.233
Design Cycle 2						
ELICIT: Clarify	0.072	0.012	6	0	0.048	0.095
APT-C: Share Reasoning	0.081	0.015	5.33	0	0.051	0.111
APT-C: Say More	0.083	0.026	3.21	0.001	0.033	0.134
APT-C: Restate	0.091	0.015	5.92	0	0.061	0.121
APT-C: Add More	0.094	0.024	3.9	0	0.047	0.142
DECLARE: Inform	0.101	0.009	11.08	0	0.083	0.118
APT-F: Press Reasoning	0.129	0.042	3.06	0.002	0.046	0.212
DECLARE: Present	0.130	0.011	11.61	0	0.108	0.153
SUGGEST: Response	0.179	0.010	17.56	0	0.159	0.199
Sample of Conversations						
DECLARE: Activity	0.051	0.015	3.48	0.001	0.022	0.080
DECLARE: POV	0.070	0.011	6.16	0	0.048	0.093
APT-F: Say More	0.076	0.024	3.12	0.002	0.028	0.124
APT-F: Press Reasoning	0.083	0.025	3.4	0.001	0.035	0.132
APT-F: Challenge	0.085	0.016	5.31	0	0.053	0.116
APT-C: Explain	0.091	0.011	8.03	0	0.068	0.113
ELICIT: Pose	0.098	0.011	8.75	0	0.076	0.120
APT-C: Say More	0.101	0.016	6.24	0	0.069	0.132
ELICIT: Clarify	0.106	0.010	10.37	0	0.086	0.126
SUGGEST: Approach	0.119	0.018	6.45	0	0.083	0.156
APT-C: Add More	0.131	0.013	9.74	0	0.105	0.158
DECLARE: Inform	0.133	0.008	15.76	0	0.117	0.150
APT-C: Restate	0.136	0.011	12.37	0	0.115	0.158
APT-C: Share Reasoning	0.142	0.009	15.81	0	0.124	0.160
APT-F: Revoice	0.153	0.019	8	0	0.116	0.191
SUGGEST: Response	0.178	0.009	19.64	0	0.160	0.196
DECLARE: Present	0.186	0.009	20.78	0	0.169	0.204
Knowledge of Manufacturing						
Conversation 2						
DECLARE: Activity	0.082	0.034	2.4	0.017	0.015	0.148
APT-C: Explain	0.129	0.027	4.84	0	0.077	0.181
APT-F: Challenge	0.134	0.037	3.64	0	0.062	0.206
DECLARE: Inform	0.151	0.023	6.68	0	0.107	0.196
APT-C: Say More	0.170	0.033	5.21	0	0.106	0.234
APT-C: Add More	0.173	0.032	5.49	0	0.111	0.235
DECLARE: POV	0.186	0.020	9.19	0	0.146	0.226
ELICIT: Clarify	0.190	0.023	8.43	0	0.146	0.234

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
ELICIT: Pose	0.224	0.018	12.32	0	0.188	0.259
APT-F: Press Reasoning	0.259	0.034	7.58	0	0.192	0.326
APT-C: Share Reasoning	0.260	0.017	15.47	0	0.227	0.293
DECLARE: Present	0.273	0.022	12.51	0	0.231	0.316
SUGGEST: Response	0.276	0.018	15.76	0	0.242	0.311
SUGGEST: Approach	0.279	0.028	10.11	0	0.225	0.333
APT-C: Restate	0.290	0.020	14.32	0	0.250	0.329
APT-F: Revoice	0.309	0.042	7.3	0	0.226	0.393
Conversation 3						
ELICIT: Clarify	0.062	0.018	3.39	0.001	0.026	0.098
APT-C: Say More	0.088	0.034	2.61	0.009	0.022	0.153
APT-C: Share Reasoning	0.093	0.022	4.17	0	0.049	0.136
ELICIT: Pose	0.099	0.021	4.63	0	0.057	0.141
DECLARE: Inform	0.114	0.013	8.91	0	0.089	0.139
DECLARE: Present	0.141	0.014	9.86	0	0.113	0.169
APT-C: Restate	0.153	0.017	8.95	0	0.119	0.186
SUGGEST: Response	0.214	0.013	16.27	0	0.188	0.240
Conversation 4						
DECLARE: Inform	0.048	0.011	4.39	0	0.026	0.069
APT-C: Restate	0.051	0.017	2.98	0.003	0.017	0.084
ELICIT: Clarify	0.056	0.012	4.63	0	0.032	0.080
SUGGEST: Response	0.064	0.016	3.91	0	0.032	0.097
Design Cycle 1						
SUGGEST: Process	0.052	0.019	2.7	0.007	0.014	0.089
DECLARE: Activity	0.060	0.023	2.67	0.007	0.016	0.105
APT-C: Explain	0.080	0.017	4.68	0	0.046	0.113
APT-F: Challenge	0.083	0.023	3.64	0	0.038	0.127
APT-F: Say More	0.091	0.031	2.94	0.003	0.030	0.152
DECLARE: POV	0.101	0.014	7.24	0	0.074	0.129
APT-C: Add More	0.120	0.019	6.23	0	0.082	0.158
APT-C: Say More	0.122	0.020	6.16	0	0.083	0.161
DECLARE: Inform	0.135	0.014	9.38	0	0.107	0.164
APT-F: Press Reasoning	0.137	0.022	6.26	0	0.094	0.180
ELICIT: Clarify	0.139	0.015	9.08	0	0.109	0.169
ELICIT: Pose	0.157	0.013	11.97	0	0.131	0.183
APT-C: Share Reasoning	0.157	0.012	13.03	0	0.134	0.181
APT-F: Revoice	0.177	0.026	6.9	0	0.127	0.228
APT-C: Restate	0.189	0.014	13.25	0	0.161	0.217
SUGGEST: Response	0.197	0.013	15.12	0	0.172	0.223
DECLARE: Present	0.198	0.013	15.02	0	0.172	0.224

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
SUGGEST: Approach	0.223	0.020	11.33	0	0.184	0.261
Design Cycle 2						
ELICIT: Pose	0.058	0.017	3.46	0.001	0.025	0.091
APT-C: Share Reasoning	0.064	0.016	4.07	0	0.033	0.095
ELICIT: Clarify	0.065	0.012	5.57	0	0.042	0.088
DECLARE: Inform	0.089	0.009	10	0	0.072	0.107
DECLARE: Present	0.114	0.011	10.41	0	0.093	0.136
APT-C: Restate	0.115	0.013	9.12	0	0.090	0.139
SUGGEST: Response	0.170	0.010	17.32	0	0.150	0.189
Sample of Conversations						
APT-C: Explain	0.044	0.014	3.08	0.002	0.016	0.072
APT-F: Challenge	0.049	0.019	2.6	0.009	0.012	0.087
DECLARE: POV	0.068	0.012	5.8	0	0.045	0.091
APT-C: Add More	0.085	0.017	5.06	0	0.052	0.118
ELICIT: Clarify	0.091	0.011	8.11	0	0.069	0.113
APT-C: Say More	0.092	0.017	5.54	0	0.059	0.124
DECLARE: Inform	0.105	0.010	10.79	0	0.086	0.124
APT-F: Press Reasoning	0.113	0.019	5.88	0	0.075	0.150
ELICIT: Pose	0.117	0.011	10.72	0	0.096	0.138
APT-C: Share Reasoning	0.122	0.010	12.04	0	0.102	0.142
APT-F: Revoice	0.132	0.021	6.33	0	0.091	0.173
SUGGEST: Approach	0.150	0.016	9.27	0	0.118	0.181
APT-C: Restate	0.151	0.011	13.57	0	0.129	0.173
DECLARE: Present	0.153	0.010	14.93	0	0.133	0.174
SUGGEST: Response	0.186	0.010	18.9	0	0.167	0.205
Knowledge of Materials						
Conversation 1						
SUGGEST: Role	0.028	0.010	2.81	0.005	0.008	0.047
ADMIN: Pose	0.034	0.008	4.44	0	0.019	0.049
ADMIN: State	0.035	0.008	4.31	0	0.019	0.050
DECLARE: Inform	0.035	0.008	4.31	0	0.019	0.050
DECLARE: Present	0.037	0.007	5.09	0	0.023	0.052
ELICIT: Clarify	0.037	0.008	4.59	0	0.021	0.053
Conversation 2						
DECLARE: POV	0.038	0.013	2.85	0.004	0.012	0.063
ELICIT: Pose	0.045	0.012	3.83	0	0.022	0.068
DECLARE: Inform	0.050	0.012	4.23	0	0.027	0.073
APT-C: Share Reasoning	0.053	0.011	4.97	0	0.032	0.075
SUGGEST: Response	0.066	0.011	6.16	0	0.045	0.087
ADMIN: State	0.067	0.011	5.89	0	0.045	0.089

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
APT-C: Say More	0.078	0.014	5.72	0	0.051	0.104
DECLARE: Present	0.088	0.011	7.75	0	0.066	0.111
APT-F: Revoice	0.098	0.019	5.3	0	0.062	0.135
APT-C: Restate	0.105	0.011	10.03	0	0.085	0.126
Conversation 3						
ADMIN: State	-0.188	0.070	-2.69	0.007	-0.324	-0.051
ADMIN: Pose	-0.176	0.057	-3.07	0.002	-0.288	-0.063
ELICIT: Process	-0.110	0.048	-2.31	0.021	-0.203	-0.017
APT-C: Share Reasoning	0.093	0.033	2.8	0.005	0.028	0.158
DECLARE: Inform	0.152	0.015	10.16	0	0.122	0.181
DECLARE: Present	0.256	0.018	13.9	0	0.220	0.292
APT-C: Restate	0.261	0.027	9.76	0	0.208	0.313
SUGGEST: Response	0.265	0.020	13.41	0	0.227	0.304
DECLARE: Activity	0.267	0.018	14.99	0	0.232	0.302
Conversation 4						
DECLARE: Inform	0.049	0.011	4.24	0	0.026	0.071
APT-C: Restate	0.055	0.019	2.91	0.004	0.018	0.091
SUGGEST: Response	0.061	0.019	3.22	0.001	0.024	0.098
Design Cycle 1						
ELICIT: Pose	0.025	0.009	2.85	0.004	0.008	0.042
APT-C: Share Reasoning	0.031	0.007	4.36	0	0.017	0.044
ELICIT: Clarify	0.032	0.009	3.45	0.001	0.014	0.050
APT-F: Say More	0.035	0.015	2.35	0.019	0.006	0.065
ADMIN: Pose	0.039	0.008	4.73	0	0.023	0.055
DECLARE: Inform	0.043	0.007	5.86	0	0.029	0.058
APT-C: Say More	0.046	0.010	4.85	0	0.028	0.065
SUGGEST: Response	0.047	0.008	6.13	0	0.032	0.062
ADMIN: State	0.051	0.007	7.07	0	0.037	0.066
APT-F: Revoice	0.058	0.014	4.25	0	0.031	0.085
DECLARE: Present	0.060	0.007	8.67	0	0.047	0.074
APT-C: Restate	0.071	0.007	9.99	0	0.057	0.085
Design Cycle 2						
ADMIN: Pose	-0.150	0.046	-3.28	0.001	-0.240	-0.060
ADMIN: State	-0.139	0.046	-3.05	0.002	-0.229	-0.050
APT-C: Share Reasoning	0.069	0.023	3.02	0.003	0.024	0.114
DECLARE: Inform	0.136	0.011	12.41	0	0.114	0.157
APT-C: Restate	0.196	0.019	10.49	0	0.160	0.233
SUGGEST: Response	0.224	0.015	15.16	0	0.195	0.253
DECLARE: Activity	0.230	0.014	16.91	0	0.204	0.257
DECLARE: Present	0.236	0.014	16.47	0	0.208	0.264

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
Sample of Conversations						
APT-C: Add More	-0.093	0.047	-2	0.046	-0.184	-0.002
APT-C: Share Reasoning	0.033	0.010	3.22	0.001	0.013	0.054
ELICIT: Clarify	0.045	0.010	4.35	0	0.025	0.065
APT-C: Say More	0.054	0.017	3.2	0.001	0.021	0.087
DECLARE: Inform	0.116	0.006	18.39	0	0.104	0.128
SUGGEST: Response	0.133	0.008	16.87	0	0.117	0.148
APT-C: Restate	0.136	0.009	15.25	0	0.119	0.154
DECLARE: Activity	0.138	0.008	18	0	0.123	0.153
DECLARE: Present	0.147	0.008	19.49	0	0.132	0.162
Knowledge of Surfactant						
Conversation 1						
APT-F: Challenge	0.038	0.017	2.2	0.028	0.004	0.072
APT-C: Share Reasoning	0.044	0.010	4.3	0	0.024	0.064
ELICIT: Clarify	0.053	0.014	3.88	0	0.026	0.080
APT-F: Revoice	0.072	0.025	2.9	0.004	0.023	0.121
APT-F: Say More	0.080	0.017	4.66	0	0.047	0.114
DECLARE: Inform	0.086	0.011	8.06	0	0.065	0.107
DECLARE: Present	0.089	0.010	9.24	0	0.070	0.108
SUGGEST: Approach	0.098	0.045	2.19	0.028	0.010	0.185
Conversation 2						
ADMIN: Pose	-0.245	0.121	-2.03	0.043	-0.481	-0.008
ELICIT: Clarify	0.162	0.028	5.8	0	0.107	0.217
APT-C: Say More	0.169	0.038	4.41	0	0.094	0.244
APT-F: Say More	0.184	0.052	3.56	0	0.083	0.285
APT-F: Press Reasoning	0.192	0.049	3.94	0	0.097	0.288
DECLARE: Inform	0.193	0.023	8.3	0	0.147	0.238
APT-C: Add More	0.227	0.033	6.87	0	0.162	0.291
APT-C: Explain	0.244	0.023	10.56	0	0.199	0.289
ELICIT: Pose	0.252	0.020	12.76	0	0.213	0.291
APT-F: Challenge	0.256	0.032	8.04	0	0.194	0.318
DECLARE: POV	0.272	0.020	13.67	0	0.233	0.311
SUGGEST: Approach	0.272	0.034	7.91	0	0.205	0.340
APT-F: Revoice	0.300	0.055	5.48	0	0.193	0.407
APT-C: Share Reasoning	0.332	0.017	19.41	0	0.299	0.366
SUGGEST: Response	0.362	0.018	19.93	0	0.327	0.398
DECLARE: Present	0.386	0.024	16.13	0	0.339	0.433
APT-C: Restate	0.408	0.022	18.44	0	0.365	0.451
Conversation 3						
APT-C: Explain	0.118	0.037	3.16	0.002	0.045	0.191

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
SUGGEST: Approach	0.126	0.047	2.65	0.008	0.033	0.218
ELICIT: Clarify	0.154	0.020	7.74	0	0.115	0.193
ELICIT: Pose	0.159	0.027	5.9	0	0.106	0.211
APT-C: Add More	0.178	0.049	3.66	0	0.083	0.273
APT-C: Share Reasoning	0.198	0.024	8.24	0	0.151	0.245
DECLARE: Inform	0.201	0.016	12.49	0	0.170	0.233
APT-F: Revoice	0.229	0.051	4.45	0	0.128	0.330
APT-C: Restate	0.232	0.022	10.63	0	0.189	0.275
DECLARE: Present	0.232	0.018	12.99	0	0.197	0.267
SUGGEST: Response	0.324	0.016	19.77	0	0.292	0.356
Conversation 4						
DECLARE: Inform	0.035	0.009	3.85	0	0.017	0.052
SUGGEST: Response	0.045	0.014	3.27	0.001	0.018	0.071
APT-C: Restate	0.046	0.013	3.58	0	0.021	0.071
Design Cycle 1						
ADMIN: Action	-0.202	0.095	-2.13	0.033	-0.387	-0.016
APT-C: Say More	0.096	0.026	3.66	0	0.045	0.147
ELICIT: Clarify	0.121	0.020	6.2	0	0.083	0.159
APT-C: Add More	0.123	0.024	5.22	0	0.077	0.169
APT-C: Explain	0.124	0.017	7.28	0	0.091	0.158
DECLARE: POV	0.129	0.015	8.39	0	0.099	0.160
APT-F: Challenge	0.139	0.022	6.39	0	0.096	0.181
APT-F: Say More	0.148	0.029	5.04	0	0.090	0.206
DECLARE: Inform	0.165	0.016	10.05	0	0.132	0.197
ELICIT: Pose	0.169	0.016	10.8	0	0.138	0.200
APT-C: Share Reasoning	0.186	0.014	13.44	0	0.158	0.213
APT-F: Revoice	0.189	0.034	5.58	0	0.123	0.256
SUGGEST: Approach	0.228	0.027	8.46	0	0.175	0.280
DECLARE: Present	0.232	0.016	14.94	0	0.202	0.262
APT-C: Restate	0.248	0.017	14.95	0	0.215	0.280
SUGGEST: Response	0.250	0.015	16.52	0	0.220	0.279
Design Cycle 2						
APT-C: Add More	0.097	0.033	2.96	0.003	0.033	0.161
ELICIT: Pose	0.100	0.019	5.21	0	0.062	0.137
SUGGEST: Approach	0.101	0.033	3.09	0.002	0.037	0.166
ELICIT: Clarify	0.105	0.014	7.55	0	0.078	0.132
APT-C: Share Reasoning	0.119	0.017	6.98	0	0.085	0.152
APT-F: Revoice	0.146	0.034	4.28	0	0.079	0.213
DECLARE: Inform	0.148	0.011	13.54	0	0.127	0.170
APT-C: Restate	0.168	0.015	11.1	0	0.138	0.197

	dy/dx (Pr)	Delta-Method Std. Err.	z	P>|z|	Lower 95% CI	Upper 95% CI
DECLARE: Present	0.183	0.013	14.25	0	0.158	0.208
SUGGEST: Response	0.239	0.012	20.4	0	0.216	0.262
Sample of Conversations						
ADMIN: Action	-0.190	0.082	-2.33	0.02	-0.350	-0.030
ADMIN: Pose	-0.085	0.032	-2.67	0.008	-0.147	-0.022
ELICIT: Process	-0.074	0.034	-2.17	0.03	-0.141	-0.007
ADMIN: State	-0.070	0.030	-2.35	0.019	-0.128	-0.011
SUGGEST: Process	-0.049	0.023	-2.12	0.034	-0.094	-0.004
APT-F: Press Reasoning	0.066	0.031	2.14	0.032	0.006	0.125
APT-C: Say More	0.084	0.021	4.04	0	0.043	0.124
APT-C: Explain	0.091	0.013	7	0	0.066	0.117
ELICIT: Clarify	0.097	0.012	7.87	0	0.073	0.121
DECLARE: POV	0.099	0.012	8.51	0	0.076	0.122
APT-F: Challenge	0.100	0.017	5.82	0	0.067	0.134
APT-C: Add More	0.112	0.018	6.18	0	0.077	0.148
APT-F: Say More	0.120	0.023	5.23	0	0.075	0.164
DECLARE: Inform	0.141	0.010	14.73	0	0.122	0.160
ELICIT: Pose	0.142	0.012	12.24	0	0.119	0.164
APT-C: Share Reasoning	0.163	0.010	16.09	0	0.143	0.183
APT-F: Revoice	0.165	0.025	6.72	0	0.117	0.213
SUGGEST: Approach	0.167	0.020	8.51	0	0.129	0.206
DECLARE: Present	0.201	0.010	19.27	0	0.181	0.222
APT-C: Restate	0.203	0.012	17.62	0	0.181	0.226
SUGGEST: Response	0.244	0.010	24.72	0	0.225	0.263

Bibliography

ABET. (2011). Criteria for Accrediting Engineering Programs.

Adamson, D., Ashe, C., Jang, H., Yaron, D., & Rosé, C. (2013). Intensification of group knowledge exchange with academically productive talk agents. In *Proceedings of the 10th International Conference on Computer Supported Collaborative Learning*, Madison, Wisconsin.

Adamson, D., Dyke, G., Jang, H., & Rosé, C. P. (2014). Towards an agile approach to adapting dynamic collaboration support to student needs. *International Journal of Artificial Intelligence in Education*, *24*(1), 92-124.

Adamson, D. & Rosé, C. P. (2012). Coordinating Multi-Dimensional Support in Conversational Agents, Proceedings of the 11th International Conference on Intelligent Tutoring Systems, LNCS Volume 7315, Springer-Verlag, pp 346-351.

Ai, H., Kumar, R., Nguyen, D., Nagasunder, A., & Rosé, C. P. (2010). Exploring the effectiveness of social capabilities and goal alignment in computer supported collaborative learning. In *Intelligent Tutoring Systems* (pp. 134-143). Springer Berlin Heidelberg.

Alexander, P. A. (2003). The development of expertise: The journey from acclimation to proficiency. *Educational Researcher, 32*(8), 10-14.

Alliance for, E. E. (2011). A time for deeper learning: Preparing students for a changing world. Policy brief. Alliance for Excellent Education.

American Association of Colleges and Universities. (2007). College learning for the new global century. Washington, DC: AACU.

Ananiadou, K., & Claro, M. (2009). 21st century skills and competences for new millennium learners in OECD countries. O*ECD Education Working Papers, OECD Publishing* (41). doi:http://dx.doi.org/10.1787/218525261154

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher, 25*(4), 5-11

Anderson, L.W. (Ed.), Krathwohl, D.R. (Ed.), Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Pintrich, P.R., Raths, J., & Wittrock, M.C. (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of Educational Objectives (Complete edition). New York: Longman.

Andrews, D. H., Nullmeyer, R. T., Good, J., and Fitzgerald, P. C. (2008). Measurement of learning processes in pilot simulation. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Annetta, L. A. (2010). The I's have it: A framework for serious educational game design. *Review of General Psychology*, *14*, 105–112

Arastoopour, G., Chesler, N., D'Angelo, C., Shaffer, D.W., Opgenorth, J., Reardan, C., Haggerty, N., & Lepak, C. (2012). Nephrotex: Measuring first-year students' ways of professional thinking in a virtual internship. Paper presented at the annual meeting of the American Society of Engineering Education. San Antonio, TX. Available at: http://edgaps.org/gaps/wp-content/uploads/Arastoopour2012.pdf

Arastoopour, G., Chesler, N. C., & Shaffer, D. W. (2014). Epistemic Persistence: A Simulation-Based Approach to Increasing Participation of Women in Engineering. *Journal of Women and Minorities in Science and Engineering*, 20(3).

Arastoopour, G. & Shaffer, D.W. (2013). Measuring social identity development in epistemic games. Paper presented at the International Conference on Computer Supported Learning. Madison, WI. Available at: http://edgaps.org/gaps/wp-content/uploads/CSCL2013_Identity_final.pdf.

Assessment and Teaching of 21st Century Skills (ATC21S). (n.d.). Retrieved from http://atc21s.org/.

Bagley, E. A., & Shaffer, D. W. (2011). *Stop talking and type: Mentoring in a virtual and face-to-face environmental education environment*. *Department of Learning Sciences*. University of Wisconsin-Madison, Madison.

Bagley, E.A., & Shaffer, D.W. (2009). When people get in the way: Promoting civic Thinking through epistemic game play. *International Journal of Gaming and Computer Mediated Simulations, 1*, 36–52.

Baker, E. L., Niemi, D. & Chung, G. K.W.K. (2008). Simulations and the Transfer of Problem-Solving Knowledge and Skills. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Baker, E. L., & O'Neil Jr., H. F. (2002). Measuring problem solving in computer environments: Current and future states. *Computers in Human Behavior, 18*(6), 609.

Barab, S., Pettyjohn, P., Gresalfi, M., Volk, C., & Solomou, M. (2012). Game-based Curriculum and transformational play: Designing to meaningfully positioning person, content, and context. *Computers & Education, 58*(1), 518-533.

Bartus, T. (2005). Estimation of marginal effects using margeff. *The Stata Journal, 5*(3), 309-329.

Bear, J. & Woolley, A.W. (2011). The role of gender in team collaboration and performance. *Interdisciplinary Science Reviews, 36*(2), 146-153.

Bedolla, L. G. (2010). 21st century competencies and civic participation. A paper for the National Research Council on behalf of the Hewlett Foundation. Retrieved 03/02/2011 from http://www.hewlett.org/programs/education program/deeper-learning.

Behrens, J. T., Frezzo, D., Mislevy, R., Kroopnick, M., & Wise, D. (2008). Structural, functional, and semiotic symmetries in simulation-based games and assessments. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Behrens, J. T., Mislevy, R. J., DiCerbo, K. E. & Levy, R. (2012). Evidence centered design for learning and assessment in the digital world. In M.C. Mayrath, J. Clarke-Midura, D.H. Robinson, G. Schraw (Eds.), *Technology-based Assessments for 21st Century Skills: Theoretical and Practical Implications from Modern Research*. Charlette, NC: Information Age Publishing, Inc.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *Clearing House: A Journal of Educational Strategies, Issues and Ideas, 83*(2), 39-43.

Bennett, R. E. (2010). Cognitively based assessment of, for, and as learning (CBAL): A preliminary theory of action for summative and formative assessment. *Measurement: Interdisciplinary Research & Perspective, 8*(2-3), 70-91.

Bennett, R. E. (2011b). Formative assessment: A critical review. *Assessment in Education: Principles, Policy & Practice, 18*(1), 5-25. doi:10.1080/0969594X.2010.513678

Bennett, R. E., & Gitomer, D. H. (2009). Transforming K–12 assessment: Integrating accountability testing, formative assessment, and professional support. In C. Wyatt-Smith & J. Cumming (Eds.), *Educational assessment in the 21st century* (pp. 43–61). New York, NY: Springer.

Bergman, D. J. (2010). Why do we have to learn this? Teaching goals beyond content. *Clearing House, 83*(4), 129-132. doi:10.1080/00098651003705905

Berkowitz, M., & Gibbs, J. (1979). A Preliminary Manual for Coding Transactive Features of Dyadic Discussion. Unpublished manuscript, Marquette University, 2(1).

Berkowitz, M., & Gibbs, J. (1983). Measuring the developmental features of moral discussion. *Merrill-Palmer Quarterly*, 29, 399-410.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M. & Rumble, M. (2012). Defining 21st century skills. In P. Griffin, B., Care, E., & McGaw, B. (Eds.), *Assessment and Teaching of 21st Century Skills***,** Springer.

Black, P., & Wiliam, D. (2007). Large-scale assessment systems: Design principles drawn from international comparisons. *Measurement: Interdisciplinary Research and Perspectives, 5*(1), 1-53.

Bloomer, A., Griffiths, P., Merrison, A. J., & Merrison, A. (2005). *Introducing language in use: a coursebook*. Psychology Press.

Blumenfeld, P. C., Marx, R. W., Soloway, E., & Krajcik, J. (1996). Learning with peers: From small group cooperation to collaborative communities. *Educational researcher*, 37-40.

Bluemink, J., Hämäläinen, R., Manninen, T., & Järvelä, S. (2010). Group-level analysis on multiplayer game collaboration: How do the individuals shape the group interaction?. *Interactive Learning Environments*, *18*(4), 365-383.

Bockarjova, M., & Hazans, M. (2000). Marginal effects distributions in logit models of labour markets. EuroFaculty Working Paper. Retrieved June 10, 2015 from: http://www.ibrarian.net/navon/page.jsp?paperid=279715&searchTerm=marginal+models

Boots, N.K., & Strobel, J. (2014). Equipping the designers of the future: Best practices of epistemic video game design*.* *Games and Culture*, *9*(3), 167-181.

Bouton, C., & Garth, R. Y. (1983). Students in learning groups: Active learning through conversation. *New Directions for Teaching and Learning*, (14), 73-82.

Boyatzis, R. E. (2008). Competencies in the 21st century. *Journal of Management Development, 27*(1), 5-5-12. doi:DOI 10.1108/02621710810840730

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education, 24*, 61-100.

Bransford, J., Brown, A. L., Cocking, R. R., & National Research Council (US) Committee on Developments in the Science of Learning. (2000). *How people* *learn: Brain, mind, experience, and school*. Washington, D.C.: National Academy Press.

Brown, A.L., & Campione, J.C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education* (pp. 289–325). Mahwah, NJ: Erlbaum.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1), 32–42.

Brown, J. S., & Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organization Science, 2*(1), 40-57.

Buck Institute for Education (2011). Review of 21st century skills frameworks. Retrieved 10/11/11 from http://www.bie.org/research/21st_century_skills

Cakir, M., Xhafa, F., Zhou, N., & Stahl, G. (2005). Thread-based analysis of patterns of collaborative interaction in chat. In *Artificial Intelligence in Education (AIED)*, 120-127.

Cascio, W. F. (2010). The relationship of 21st century competencies to important personal and work outcomes. A paper for the National Research Council on behalf of the Hewlett Foundation. Retrieved 03/02/2011 from http://www.hewlett.org/programs/education program/deeper-learning

Chaudhuri, S., Kumar, R., Howley, I. K., & Rosé, C. P. (2009). Engaging Collaborative Learners with Helping Agents. In *Artificial Intelligence in Education (AIED)*, 365-372.

Cheng, S.C. (2014). *Effects of Socio-cognitive Conflicts on Group Cognition and Group Performance* (unpublished doctoral dissertation). Harvard Graduate School of Education, Cambridge, MA.

Chesler, N. C., Arastoopour, G., D'Angelo, C. M., Bagley, E. A., & Shaffer, D. W. (2013). Design of a Professional Practice Simulator for Educating and Motivating First-Year Engineering Students. *Advances in Engineering Education*, 3(1), 1-29.

Choi, Y., Rupp, A., Gushta, M., & Sweet, S. (2010). Modeling learning trajectories with epistemic network analysis: An investigation of a novel analytic method for learning progressions in epistemic games. *National Council on Measurement in Education*, 1-39.

Chung, G. K. W. K., Harmon, T. C., & Baker, E. L. (2001). The impact of a simulation Based learning design project on student learning. *IEEE Transactions on Education, 44*(4), 390.

Clarke-Midura, J., & Dede, C. (2010). Assessment, technology, and change. *Journal of Research on Technology in Education, 42*(3), 309-328.

Clarke-Midura, J., Code, J., Dede, C, Mayrath, M. & Zap, N. (2012). Thinking outside the bubble: Virtual performance assessments for measuring complex learning. In M.C. Mayrath, J. Clarke-Midura, D.H. Robinson, G. Schraw (Eds.), *Technology-based Assessments for 21st Century Skills: Theoretical and Practical Implications from Modern Research*. Charlette, NC: Information Age Publishing, Inc.

Coatsworth, J. D. (2010). A Developmental Psychopathology and Resilience Perspective on 21st Century Competencies. A paper for the National Research Council on behalf of the Hewlett Foundation. Retrieved 03/02/2011 from http://www.hewlett.org/programs/education-program/deeper-learning.

Common Core. (2011). A challenge to the Partnership for 21st Century Skills. Retrieved from http://www.commoncore.org/p21-challenge.php.

Common Core State Standards Initiative. (n.d.). Retrieved from http://www.corestandards.org/.

Conejo, R., Barros, B., Guzmán, E., & Garcia-Viñas, J. I. (2013). A web based collaborative testing environment. *Computers & Education*, *68*, 440-457.

Conley, D. T. (2007). *Toward a more comprehensive conception of college readiness*. Eugene, OR: Educational Policy Improvement Center.

Costa, A. L., Kallick, B., & Association for Supervision and Curriculum Development. (2000). *Discovering & exploring habits of mind. A developmental series, book 1.*

CRESST/O'Neil, H. F., Allred, K. and Baker, E. L. (1992). Measurement of Workforce Readiness: Review of Theoretical Frameworks. (CSE Technical Report 343). Los Angeles, CA: CRESST UCLA Graduate School of Education. Retrieved October 15, 2011 from: *www.cse.ucla.edu/products/reports/TECH343.pdf*

D'Angelo, C., Shaffer, D. W., & Chesler, N. (2011). Undergraduate Engineers Engaging and Reflecting in a Professional Practice Simulation. Paper presented at American Society for Engineering Education (ASEE), Vancouver, British Columbia.

Darling-Hammond, L. & Adamson, F. (2010). *Beyond basic skills: The role of performance assessment in achieving 21st century standards of learning.* Stanford, CA: Stanford University, Stanford Center for Opportunity Policy in Education.

Darling-Hammond, L., & Pecheone, R. L. (2009). Reframing accountability: Using performance assessments to focus learning on higher-order skills. In L. M. Pinkus (Ed.), *Meaningful measurement: The role of assessments in improving high school education in the twenty-first century*. Washington, D.C.: Alliance for Excellent Education.

Darling-Hammond, L., Noguera, P., & Friedlaender, D. (2015). Equal opportunity for deeper learning. Students at the Center: Deeper Learning Research Series. Boston, MA: Jobs for the Future.

Dede, C. (2007). Reinventing the Role of Information and Communications Technologies in Education. In L. Smolin, K. Lawless, & N. Burbules (Eds.), Information and Communication Technologies: Considerations of Current Practice for Teachers and Teacher Educators [NSSE Yearbook 2007 (106:2)]. Malden, MA: Blackwell Publishing.

Dede, C. (2010). Comparing Frameworks for 21st Century Skills. In J. Bellanca & R. Brandt, Eds, 21st Century Skills, pp. 51-76.. Bloomington, IN: Solution Tree Press.

Dede, C. (2011). Reconceptualizing technology integration to meet the challenges of educational transformation. *Journal of Curriculum and Instruction, 5*(1), 4–16.

Dede, C. (2014). The role of digital technologies in deeper learning. Students at the Center: Deeper Learning Research Series. Boston, MA: Jobs for the Future.

Department of Labor, Washington, DC Secretary's Commission on Achieving Necessary Skills. (1991). *Skills and tasks for jobs. A SCANS report for america 2000.*

Dieterle, E. (2009). Multi-User Virtual Environments for Teaching and Learning. In M.Pagani (Ed.), *Encyclopedia of Multimedia Technology and Networking, Second Edition* (pp. 1033-1041). Hershey, PA: Information Science Reference.

Dillenbourg, P. (1999). What do you mean by collaborative learning?. *Collaborative-learning: Cognitive and Computational Approaches*, 1-19.

Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1995). The evolution of research on collaborative learning. In E. Spada & P. Reiman (Eds.), *Learning in Humans and Machine: Towards an interdisciplinary learning science*, 189–211.

DiMartino, J., & Castaneda, A. (2007). Assessing applied skills. *Educational Leadership, 64*(7), 38-42.

Dweck, C. (2009). Who will the 21st-century learners be? *Knowledge Quest, 38*(2), 8-9.

Dyke, G., Howley, I., Adamson, D., Kumar, R., & Rosé, C. P. (2013). Towards academically productive talk supported by conversational agents. In *Productive multivocality in the analysis of group interactions* (pp. 459-476). Springer US.

Epistemic Network Analysis (ENA) (2014). http://epistemicgames.org/ena/.

Finegold, D., & Notabartolo, A. S. (2010). 21st-century competencies and their impact: An interdisciplinary literature review. A paper for the National Research Council on behalf of the Hewlett Foundation. Retrieved 03/02/2011 from http://www.hewlett.org/programs/education-program/deeper-learning.

Fischer, F., Bruhn, J., Gräsel, C., & Mandl, H. (2002). Fostering collaborative knowledge construction with visualization tools. *Learning and Instruction*, 12, 213-232.

Fischer, F., & Mandle, H. (2001). Facilitating the construction of shared knowledge with graphical representation tools in face-to-face and computer-mediated scenarios. In P. Dillenbourg, A. Eurelings, & K. Hakkarainen (Eds.), *European perspectives on computer-supported collaborative learning* (pp. 230-236). Masstricht, NL: University of Maastricht.

Fleiss, J. L. (1981). *Statistical methods for rates and proportions* (2nd ed.). New York: John Wiley.

Fletcher, J. D. & Morrison, J. E.. (2008). Representing cognition in games and simulations. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Frederiksen, J. R., & Collins, A. (1989). A systems approach to educational testing. *Educational Researcher, 18*(9), pp. 27-32.

Frederiksen, N. (1984). The real test bias: Influences of testing on teaching and learning. *American Psychologist, 39*(3), 193-202.

Frezzo, D. C., Behrens, J. T. and Mislevy, R. J. (2010). Design patterns for learning and assessment: facilitating the introduction of a complex simulation-based learning environment into a community of instructors. *Journal of Science Education and Technology*, 19(2), 105-114. doi: 10.1007/s10956-009-9192-0.

Gee, J.P. (1993). *An introduction to human language: Fundamental concepts in linguistics*. Englewood Cliffs, N.J.: Prentice Hall.

Gee, J.P. (1996). *Social linguistics and literacies: Ideology in Discourses*. Second Edition. London: Taylor & Francis.

Gee, J.P. (1999). *An Introduction to Discourse Analysis: Theory and Method*. New York: Routledge.

Gee, J. P. (2007). *What video games have to teach us about learning and literacy*, revised and updated. Basingstoke: Palgrave Macmillan.

Gee, J.P. (2008). Learning and games. In Katie Salen (Ed.), *The Ecology of Games: Connecting Youth, Games, and Learning*. The John D. and Catherine T. MacArthur Foundation Series on Digital Media and Learning. Cambridge, MA: The MIT Press, 21–40.

Giannakos, M.N. (2013). Enjoy and learn with educational games: Examining factors affecting learning performance. *Computers & Education, 68*, 429–439.

Griffin, P., McGaw, B. & Care, E., Eds. (2012). *Assessment and teaching 21st century skills*. Heidelberg: Springer.

Gunawardena, C. N., Lowe, C. A., & Anderson, T. (1997). Analysis of a global online debate and the development of an interaction analysis model for examining social construction of knowledge in computer conferencing. *Journal of educational computing research*, *17*(4), 397-431.

Hamalainen, R. (2006). Scripting collaborative learning in two different virtual game environments. In J. Enkenberg, M.B. Kenz, & O. Hatakka (Eds.), *Emerging Practices in Educational Technology*, 13-28.

Hamalainen, R. (2008). Designing and evaluating collaboration in a virtual game environment for vocational learning. *Computers & Education*, *50*(1), 98-109.

Hatano, G., & Oura, Y. (2003). Commentary: Reconceptualizing school learning using insight from expertise research. *Educational Researcher, 32*(8), 26-29.

Hatfield, D. L. (2011). *The right kind of telling: an analysis of feedback and learning in a journalism epistemic game*. Unpublished doctoral dissertation, University of Wisconsin-Madison, Madison, WI.

Hartung, K.J., & Wilson, D.G. (in press). Conversational moves that matter: Bridging learning outcomes and patterns of speech in informal cross-organizational conversations among top-level leaders. *Adult Education Quarterly.*

Hatano, G., & Oura, Y. (2003). Commentary: Reconceptualizing school learning using insight from expertise research. *Educational Researcher, 32*(8), 26-29. doi:10.3102/0013189X032008026

Hausmann, R.G.M., Chi, M.T.H., & Roy, M. (2004) Learning from collaborative problem solving: An analysis of three hypothesized mechanisms. *26nd Annual Meeting of the Cognitive Science Conference*, Chicago, IL

Hewlett Foundation. (2010a). Education Program Strategic Plan. Retrieved on 03/06/2011 from http://www.hewlett.org/uploads/documents/Education_Strategic_Plan_2010.pdf

Hewlett Foundation. (2010b). Deeper Learning Competencies. Retrieved 03/26/2011 via personal email communication.

Innovative Teaching and Learning Research. (n.d.). Retrieved from http://www.itlresearch.com/

International Society for Technology in Education (ITSE) (2007). The national Educational technology standards and performance indicators for students. Eugene, OR: ISTE.

Kapur, M., & Kinzer, C. K. (2007). Examining the effect of problem type in a synchronous computer-supported collaborative learning (CSCL) environment. *Educational Technology Research and Development, 55*(5), 439-459.

Ketelhut, D. J., Dede, C., Clarke, J., Nelson, B. & Bowman, C. (2008). Studying situated earning in a multiuser virtual environment. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Ketelhut, D. J., Nelson, B. C., Clarke, J., and Dede, C. (2010). A multi-user virtual environment for building and assessing higher order inquiry skills in science. *British Journal of Educational Technology, 41*(1), 56-68.

Kittleson, J. M., & Southerland, S. A. (2004). The role of discourse in group knowledge construction: A case study of engineering students. *Journal of Research in Science Teaching*, *41*(3), 267-293.

Klopfer, E., Osterweil, S. & Salen, K. (2009). Moving educational games forward. Cambridge MA: MIT The Education Arcade.

Kobbe, L., Weinberger, A., Dillenbourg, P., Harrer, A., Hämäläinen, R., Häkkinen, P., & Fischer, F. (2007). Specifying computer-supported collaboration scripts. *International Journal of Computer-Supported Collaborative Learning*, *2*(2), 211-224.

Koestner, R., Lekes, N., Powers, T. A., & Chicoine, E. (2002). Attaining personal goals: Self-concordance plus implementation intentions equal success. *Journal of Personality and Social Psychology, 83*, 231–244.

Kreijns, K., Kirschner, P. A., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: a review of the research. *Computers in human behavior*, *19*(3), 335-353.

Kritzenberger, H. (2012). Understanding Player Experience in Educational Games. In T. Amiel & B. Wilson (Eds.), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2012* (pp. 1329-1335). Chesapeake, VA: AACE.

Kumar, R., Ai, H., Beuth, J. L., & Rosé, C. P. (2010). Socially capable conversational tutors can be effective in collaborative learning situations. In *Intelligent Tutoring Systems* (pp. 156-164). Springer Berlin Heidelberg.

Kumar, R., & Rosé, C. P. (2011). Architecture for building conversational agents that support collaborative learning. *Learning Technologies, IEEE Transactions on Education*, 4(1), 21–34.

Kumar, R., Rosé, C. P., Wang, Y. C., Joshi, M., & Robinson, A. (2007). Tutorial dialogue as adaptive collaborative learning support. *Frontiers in artificial intelligence and applications*, 158, 383.

Kumar, V. S. (1996). Computer-supported collaborative learning: Issues for research. In *Eighth Annual Graduate Symposium on Computer Science, University of Saskatchewan*.

Lai, E. R. (2011). *Collaboration: A literature review* (Vol. 2). Pearson Research Report.

Landis, J.R., & Koch, G. (1977). The measurement of observer agreement for categorical data*. Biometrics*, 33(1), 159-174.

Larson, L. C., & Miller, T. N. (2011). 21st century skills: Prepare students for the future. *Kappa Delta Pi Record, 47*(3), 121-123.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Leonard, D. and Swarp, W. (2005). *Deep Smarts: How to Cultivate and Transfer Business Wisdom*. Boston, MA, Harvard Business School Press.

Levy, F., & Murnane, R. J. (2006). Why the changing american economy calls for twenty-first century learning: Answers to educators' questions. *New Directions for Youth Development, 2006*(110), 53-62. doi:10.1002/yd.167

Linn, R.L., Baker, E.L., & Dunbar, S.B. (1991). Complex, performance-based assessment: expectations and validation criteria. *Educational Researcher*, 20(8), 5-21.

Looney, J. W. (2009). Assessment and innovation in education. *OECD Education Working Papers, OECD Publishing*(24). doi:http://dx.doi.org/10.1787/222814543073

Markham, T., Larmer, J., & Ravitz, J. (2003). Project Based Learning Handbook: A Guide to Standards-Focused Project Based Learning for Middle and High School Teachers. Novato, CA: The Buck Institute for Education.

Mayer, R. E. (2002). A taxonomy for computer-based assessment of problem solving. *Computers in Human Behavior*, *18*(6), 623-632.

Mayer, R. E. (2008). Problem-solving assessment in games and simulation environments.In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Mayrath, M. C., Clarke-Midura, J. & Robinson, D. H. (2012). Introduction to*Technology based assessments for 21st century skills*. In M.C. Mayrath, J. Clarke-Midura, D.H. Robinson, G. Schraw (Eds.), *Technology-based Assessments for 21st Century Skills: Theoretical and Practical Implications from Modern Research*. Charlette, NC: Information Age Publishing, Inc.

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA:Harvard.

Mercer, N. (1996). The quality of talk in children's collaborative activity in the classroom. *Learning and Instruction, 6*(4), 359–377.

Metiri Group & NCREL. (2003). EnGauge 21st century skills: Literacy in the digital age. Chicago, IL: NCREL.

Michaels, S., O'Connor, C., & Resnik, L. (2008). Deliberative discourse idealized and realized: Accountable talk in the classroom and in civic life. *Studies in Philosophy and Education*, 27(4), 283-297.

Mislevy, R. J. (2008). How cognitive science challenges the educational measurement tradition. *Measurement, 6*(1), 124-124. doi:10.1080/15366360802131635

Mislevy, R. J. (2010). Some implications of expertise research for educational assessment. *Research Papers in Education, 25*(3), 253-270.

Mislevy, R. J., Almond, R. G., Lukas, J. F., & Center for Research on Evaluation, Standards, and Student Testing. (2004). *A brief introduction to evidence-centered design. CSE report 632.* ().US Department of Education.

Mislevy, R. J., & Haertel, G. D. (2006). Implications of evidence-centered design for educational testing. *Educational Measurement: Issues and Practice, 25*(4), 6-20. doi:10.1111/j.1745-3992.2006.00075.x

Molkenthin, R., Breuer, K., and Tennyson, R. D. (2008). Real-time diagnostics of Problem solving behavior for business simulations. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Moore, R.J. (2013). Ethnomethodology and conversation analysis: Empirical approaches to the study of digital technology in action. In S. Price, C. Jewitt, & B. Brown (Eds.), *The SAGE handbook of digital technology research*. Sage.

Morgan, B., Kehtkar, F., Graesser, A., & Shaffer, D.W. (2013). Automating the Mentor in a Serious Game: A Discourse Analysis Using Finite State Machines. In *HCI International 2013-Posters' Extended Abstracts* (pp. 591-595). Springer Berlin Heidelberg.

Murnane, R. & Levy, F. (1996). *Teaching the new basic skills: Principles for educating children to thrive in a changing economy*. New York: Free Press.

Nash, P., Bagley, E.A.S, & Shaffer, D.W. (2012). *Playing for Public Interest: Epistemic Games as civic engagement activities*. Paper presented at the American Educational Research Association (AERA) annual meeting, Vancouver, BC.

Nash, P. & Shaffer, D.W. (2010). Mentor modeling: the internalization of modeled professional thinking in an epistemic game. *Journal of Computer Assisted Learning*, 27(2), 173-189.

National Research Council (NRC). (2001). *Knowing what students know: The science and design of educational assessment*. Committee on the Foundations of Assessment. Pelligrino, J., Chudowsky, N., and Glaser, R., editors. Board on Testing and Assessment, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

National Research Council (NRC). (2011). *Assessing 21st Century Skills: Summary of a Workshop.* J.A. Koenig, Reporter. Committee on the Assessment of 21st Century Skills. Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council (NRC). (2012). *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century*. Committee on Defining Deeper Learning and 21st Century Skills, Pellegrino, J.W. and Hilton, M.L., Editors. Board on Testing and Assessment and Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Nephrotex. (2014). http://edgaps.org/gaps/projects/nephrotex/.

Noroozi, O., Weinberger, A., Harm, J.A., Biemans, H.J.A., Mulder, M., & Chizari, M. (2013). Facilitating argumentative knowledge construction through a transactive discussion script in CSCL. *Computers & Education*, 61, 59-76.

O'Neil, H. F. (2002). Perspectives on computer-based assessment of problem solving. *Computers in Human Behavior, 18*(6), 605-607. doi:10.1016/S0747-5632(02)00044-4

O'Neil, H. F., Chen, H., Wainess, R., and Shen, C.. (2008). Assessing problem solving in simulation games. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

O'Neil, H. F. and Chuang, S. (2008). Measuring collaborative problem solving in low

Stakes tasks. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.
O'Neil, H. F., Jr., Chung, G. K., & Brown, R. S. (1997). Use of networked simulations as a context to measure team competencies. In H. F. O'Neil (Ed.), *Workplace readiness: Competencies and assessment* (pp. 411-452). Mahwah, NJ: Lawrence Erlbaum Associates.
Organization for Economic Cooperation and Development (OECD) (2005). The definition and selection of key competencies: Executive summary. Paris, France: OECD.
Organization for Economic Cooperation and Development (OECD). (2010). Framework for PISA 2012 problem solving. Retrieved on June 3, 2012 from: www.oecd.org/dataoecd/8/42/46962005.pdf
Organization for Economic Cooperation and Development OECD. (2013). PISA 2015 Draft Collaborative Problem Solving Framework. Retrieved June 28, 2014, from http://www.oecd.org/pisa/pisaproducts/Draft%20PISA%202015%20Collaborative%20Problem%20Solving%20Framework%20.pdf
Orrill, C.H., Shaffer, D.W., & Burke, J. (2013). Exploring coherence in teacher knowledge using epistemic network analysis, *Annual Meeting, American Education Research Association,* San Francisco, CA.
Partnership for 21st Century Skills. (2006). A state leader's action guide to 21st century skills: A new vision for education. Tucson, AZ: Partnership for 21st Century Skills.
Pellegrino, J. W., Baxter, G. P., and Glaser, R. (1999). Addressing the "two disciplines" problem: linking theories of cognition and learning with assessment and instructional practice. *Review of Research in Education*, 24, 307-353.
Pellegrino, J. W., & Quellmalz, E. S. (2010). Perspectives on the integration of technology and assessment. *Journal of Research on Technology in Education, 43*(2), 119-134.
Perkins, D. N., & Salomon, G. (1989). Are cognitive skills context-bound? *Educational Researcher, 18*, 16-25.
Perkins, D. N., & Salomon, G. (1994). Transfer of learning. In T. Husen & T. N. Postelwhite (Eds.). *International Handbook of Educational Research* (Second Edition, Vol. 11; pp. 6452-6457). Oxford, Pergamon Press.
Piaget, J. (1932/1997). The moral judgement of the child. Simon and Schuster.
Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon, 9*, 2-6.
Quellmalz, E. S., & Kozma, R. (2003). Designing assessment of learning with technology. *Assessment in Education: Principles, Policy & Practice, 10*(3), 389-408.
Quellmalz, E.S., Timms, M.J. & Buckley, B.C. (2009). Recommendations for Technology and Innovation in Assessment. Retrieved from http://www2.ed.gov/programs/racetothetop-assessment/bios/quellmalz-presentation.pdf
Quellmalz, E. S., & Pellegrino, J. W. (2009). Technology and testing. *Science, 323*(5910), 75-79.

Quellmalz, E. S., Timms, M. J., Buckley, B. C., Davenport, J., Loveland, M. & Silberglitt, M. D. (2012). 21st century dynamic assessment. In M.C. Mayrath, J. Clarke-Midura, D.H. Robinson, G. Schraw (Eds.), *Technology-based Assessments for 21st Century Skills: Theoretical and Practical Implications from Modern Research*. Charlette, NC: Information Age Publishing, Inc.

Rahman, S. M., Sarkar, M. M., Gomes, J., & Mojumder, F. (2010). Students' perceptions of learning science in small groups: a case study in higher education. *International Journal of Science & Mathematics Education, 2*(1), 32-47.

Resnick, L. B. (1987). Learning in school and out. *Educational Researcher, 16*(9), 13-20.

Resnick, L. B., Asterhan, C.A., & Clarke, S.N. (2013). Socializing intelligence through academic talk and dialogue. *Washington, DC: American Educational Research Association*.

Resnick, L.B., & Resnick, D. P. (1992). Assessing the thinking curriculum: New tools for educational reform. In B.R. Gifford & M.C. O'Connor (Eds.), *Changing Assessments: Alternative views of aptitude, achievement, and instruction*. Boston: Kluwer Academic Publishers.

Resnick, L. B., Salmon, M., Zeitz, C. M., Wathen, S. H., & Holowchak, M. (1993). Reasoning in conversation. *Cognition and Instruction*, 11(3–4), 347–364.

Richmond, G. & Striley, J. (1996). Making meaning in classrooms: Social processes in small-group discourse and scienctific knowledge building. *Research in Science Education, 33*(8), 839-858.

Roschelle, J. (1992) Learning by collaborating: Convergent conceptual change. *Journal of the Learning Sciences, 2*, 235–276.

Roschelle, J. & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem-solving. In C.E. O'Malley (Ed.), *Computer-supported collaborative learning* (pp. 69–97). Berlin: Springer-Verlag.

Rosé, C.P., Goldman, P., Sherer, J.Z., & Resnick, L.B. (2015). Supportive technologies for group discussion in MOOCs. *Current Issues in Emerging eLearning*, 2(1). Retrieved from: http://scholarworks.umb.edu/cgi/viewcontent.cgi?article=1012&context=ciee

Rotherham, A. J., & Willingham, D. (2009). 21st century skills: The challenges ahead. *Educational Leadership, 67*(1), 16-21.

Rotherham, A. J., & Willingham, D. T. (2010). "21st-century" skills: Not new, but a worthy challenge. *American Educator, 34*(1), 17-20.

Rothman, R., & Alliance for, E. E. (2011). *Assessing deeper learning. Policy brief.* Alliance for Excellent Education.

Rupp, A. A., Choi, Y., Gushta, M., Mislevy, R. J., Theis, M.C., Bagley, E., Nash, P., Hatfield, D., Svarovsky, G., & Shaffer, D. (2009). Modeling learning progressions in epistemic games with epistemic network analysis: Principles for data analysis and generation. In *Proceedings from the Learning Progressions in Science Conference* (pp. 24-26).

Rupp, A.A., Gustha, M., Mislevy, R.J., & Shaffer, D.W. (2010). Evidence-centered design of epistemic games: Measurement principles for complex learning environments. *The Journal of Technology, Learning, and Assessment*, 8(4), 4-47.

Sacks, H., Schegloff, E.A., & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language, 50*, 696-735.

Sawyer, B. and Smith, P. (2008). A taxonomy of serious games. Games Developers Conference, February 2008.
Scardamalia, M., & Bereiter, C. (in press). Knowledge Building. In Encyclopedia of Education, Second Edition. New York: Macmillan Reference, USA.
Scardamalia, M., & Bereiter, C. (2003). Knowledge building environments: Extending the limits of the possible in education and knowledge work. In A. DiStefano, K.E. Rudestam, & R. Silverman (Eds.), *Encyclopedia of distributed learning.* Thousand Oaks, CA: Sage Publications.
Scardamalia, M., & Bereiter, C. (2010). A brief history of knowledge building. *Canadian Journal of Learning and Technology*. 36(1).
Scardamalia, M.; Bransford, J.; Kozma, B.; Quellmalz, E. (2012). New assessments and environments for knowledge building. In P. Griffin, B. & E. Care (Eds.), *Assessment and Teaching of 21st Century Skills*, Springer.
Schank, R. C. (2001). Educational technology: The promise and the myth. Retrieved October 27, 2011 from: http://www.socraticarts.com/docs/Educational_Technology_-_The_Promise_and_The_Myth.pdf
Schank, R. C. (n.d.). Every curriculum tells a story. Retrieved on October 27, 2011 from: http://www.socraticarts.com/docs/SCCwhitepaper.pdf
Schellens, T., & Valcke, M. (2005). Collaborative learning in asynchronous discussion groups: What about the impact on cognitive processing?. *Computers in Human Behavior, 21*(6), 957–975.
Schon, D.A. (1983). *The reflexive practitioner: How professionals think in action*. New York: Basic Books.
Schon, D.A. (1987). *Educating the reflexive practitioner: Toward a new design for teaching and learning in the professions*. San Francisco: Jossey-Bass.
Shaffer, D. W. (2004). Epistemic frames and islands of expertise: Learning from infusion experiences. In Y. Kafai, W. A. Sandoval, N. Enyedy, A. S. Nixon, & F. Herrera (Eds.), *Proceedings of the Sixth International Conference of the Learning Sciences* (pp. 473–480). Santa Monica, CA: Erlbaum.
Shaffer, D. W. (2005). Epistemic games. *Innovate*, 1(6). Retrieved on January 26, 2012 from: http://www.innovateonline.info/index.php?view=article&id=79.
Shaffer, D. W. (2006). Epistemic frames for epistemic games. *Computers and Education*, 46(3), 223–234.
Shaffer, D. W. (2007). *How Computer Games Help Children Learn*. New York: Palgrave.
Shaffer, D.W. (2014). *User guide for epistemic network analysis web version 2.0: Technical report*. Retrieved from: http://edgaps.org/gaps/wp-content/uploads/ENA-User-Guide2.pdf
Shaffer, D. W. & Gee, J. P. (2012). The right kind of GATE: Computer games and the future of assessment. In M.C. Mayrath, J. Clarke-Midura, D.H. Robinson, G. Schraw (Eds.), *Technology-based Assessments for 21st Century Skills: Theoretical and Practical Implications from Modern Research*. Charlette, NC: Information Age Publishing, Inc.
Shaffer, D. W., Hatfield, D., Svarosvsky, G. N., Nash, P., Nulty, A., Bagley, E., Frank, K., Rupp, A. A. & Mislevy, R. R. (2009). Epistemic Network Analysis: A

Prototype for 21st-Century Assessment of Learning. *International Journal of Learning and Media*, 1(2), 33-53.

Shaffer, D.W. & Resnick, M. (1999). “Thick” authenticity: New media and authentic learning. *Journal of Interactive Learning and Research,* 10(2), 195–215.

Shaffer, D. W., Squire, K. R., & Halverson, R. (2005). Video games and the future of learning. *Phi Delta Kappan, 87*(2), 104-111.

Shute, V. J. (2015). Stealth assessment. In J. M. Spector (Ed.), *Encyclopedia of Educational Technology* (pp. 675-678). Thousand Oaks, CA: Sage Publications, Inc.

Shute, V. J. & Ventura, M. (2013). *Stealth Assessment: Measuring and Supporting Learning in Video Games*. Cambridge, MA: The MIT Press.

Shute, V. J., Ventura, M., Bauer, M. I., & Zapata-Rivera, D. (2009). Melding the power of serious games and embedded assessment to monitor and foster learning: Flow and grow. In U. Ritterfeld, M. Cody, & P. Vorderer (Eds.), *Serious games: Mechanisms and effects* (pp. 295-321). Mahwah, NJ: Routledge, Taylor and Francis.

Silva, E. (2009). Measuring skills for 21st-century learning. *The Phi Delta Kappan, 90*(9), pp. 630-634.

Soller, A. (2001). Supporting social interaction in an intelligent collaborative learning system. *International Journal of Artificial Intelligence in Education* (IJAIED), 12, 40-62.

Soller, A., Goodman, B., Linton, F., & Gaimari, R. (1998). Promoting effective peer interaction in an intelligent collaborative learning system. In *Intelligent Tutoring Systems* (pp. 186-195). Springer Berlin Heidelberg.

Stahl, G. (2008). Chat on collaborative knowledge building. QWERTY. 3(1), 67-78. Retrieved from: http://gerrystahl.net/pub/qwerty08.pdf

Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.

Stahl, G., & Hesse, F. (2006). Social practices of computer-supported collaborative learning. *International Journal of Computer-Supported Collaborative Learning*, 1(4), 409-412.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409–426). Cambridge, UK: Cambridge University Press.

Stegmann, K., Weinberger, A., Fischer, F., & Mandl, H. (2004). Scripting argumentation in computer-supported learning environments. In P. Gerjets, P. A. Kirschner, J. Elen & R. Joiner (Eds.), *Instructional design for effective and enjoyable computer-supported learning*. Proceedings of the first joint meeting of the EARLI SIGs Instructional Design and Learning and Instruction with Computers (pp. 320-330). Tübingen: Knowledge Media Research Center.

Steinkuehler, C. (2006). Massively multiplayer online video gaming as participation in a discourse. *Mind, Culture, and Activity*, 13(1), 38–52.

Sternberg, R. J. (1998). Abilities are forms of developing expertise. *Educational Researcher, 27*(3), 11-20.

Storch, N. (2002). Patterns of interaction in ESL pair work. *Language Learning, 52*(1), 119–158.

Storch N. (2009*). The nature of pair interaction: Learners' interaction in an ESL class: its nature and impact on grammatical development*. Saarbrücken: VDM Verlag.

Svarovsky, G. N. (2011). Exploring Complex Engineering Learning Over Time with Epistemic Network Analysis. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(2), 4.

Svarovsky, G., and Shaffer, D.W. (2009). Modeling learning progressions in epistemic games with epistemic network analysis: Principles for data analysis and generation. *Learning Progressions in Science (LeaPS) Conf.*, Iowa City, IA.

Swarp, W., Leonard, D., Shields, M., & Abrams, L. (2001). Using mentoring and storytelling to transfer knowledge in the workplace. *Journal of management information systems*, *18*(1), 95-114.

Tannen, D. (1990). *You just don't understand: Women and men in conversation.* New York: William Morrow.

Teasley, S. D. (1997). Talking about reasoning: How important is the peer in peer collaboration? In L. B. Resnick, R. Säljö, C. Pontecorvo & B. Burge (Eds.), *Discourse, tools and reasoning: Essays on situated cognition*, 361-384.

Thomas, D., & Brown, J.S. (2009). Why virtual worlds can matter. *International Journal of Learning and Media, 1(1), 37-49.*

Toulmin, S. E. (1958). *The uses of argument*. London: Cambridge University Press.

Trilling, B., & Hood, P. (1999). Learning, technology, and education reform in the knowledge age or "we're wired, webbed, and windowed, now what?". *Educational Technology, 39*(3), 5-18.

U.S. Department of Education (USDoEd). (2010). *Transforming American education: Learning powered by technology* [National Educational Technology Plan 2010]. Washington, DC: Office of Educational Technology, U.S. Department of Education.

Van den Bossche, P., Gijselaers, W.H., Segers, M., & Kirschner, P.A. (2006). Social and cognitive factors driving teamwork in collaborative learning environments: Team learning beliefs and behaviors. *Small Group Research*, 37, 490-521.

van Gelder, T. (2005). Teaching critical thinking: Some lessons from cognitive science. *College Teaching, 53*(1), 41-46.

Vendlinski, T. P., Baker, E. L., & Niemi, D. (2008). Templates and objects in authoring problem-solving assessments. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Vygotsky, L. S. (1978). *Mind in Society: The development of higher psychological processes. Mind*. Harvard University Press.

Wagner, T. (2008a*). The Global Achievement Gap: Why Even Our Best Schools Don't Teach The New Survival Skills Our Children Need--And What We Can Do About It*. New York: Basic Books.

Wagner, T. (2008b). Rigor redefined. *Educational Leadership*, 66(2), 20-25.

Webb, N.M. (1991). Task-related verbal interaction and mathematical learning in small groups. *Research in Mathematics Education, 22*(5), 366–389.

Webb, N. M. (1995). Group collaboration in assessment: Multiple objectives, processes, and outcomes. *Educational Evaluation and Policy Analysis, 17*(2), 239-261.

Webb, N. M., & Palinscar, A. S. (1996). Group processes in the classroom. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 841–873). New York: Prentice Hall.

Webb, N. M., Nemer, K. M., Chizhik, A. W., & Sugrue, B. (1998). Equity issues in collaborative group assessment: Group composition and performance. *American Educational Research Journal, 35*(4), 607–651.

Weinberger, A., Ertl, B., Fischer, F., & Mandl, H. (2005). Epistemic and social scripts in computer-supported collaborative learning. *Instructional Science, 33*(1), 1-30.

Weinberger, A. & Fischer, F. (2006). A framework to analyze argumentative knowledge construction in computer-supported collaborative learning. *Computers and Education*, 46(1), 71-95.

Weinberger, A., Stegmann, K., & Fischer, F. (2007). Knowledge convergence in collaborative learning: Concepts and assessment. *Learning and Instruction*, 17 (4), 416-426.

Wenger, E. (1999). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press.

Wilson, D.G., & Hartung, K.J. (2015). Types of informal learning in cross-organizational collegial conversations. *Journal of Workplace Learning, 27*(8), p. 596-610.

Wiley, D., & Waters, S. (2005). Scoping and sequencing educational resources and speech acts: A unified design framework for learning objects and educational discourse. *Interdisciplinary Journal of E-Learning and Learning Objects*, *1*(1), 143-150.

Wisher, R. A. (2008). Assessing problem-solving performance.. In E. Baker, J. Dickieson, W. Wufeck, H. O'Neill (Eds.), *Assessment of Problem Solving Using Simulations*. New York, NY: Taylor & Francis Group, LLC.

Wolters, C. A. (2010). Self-regulated learning and the 21st century competencies. A paper for the National Research Council on behalf of the Hewlett Foundation. Retrieved 03/02/2011 from http://www.hewlett.org/programs/education-program/deeper-learning.

Wooley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. S*cience*, *330*(6004), 686-688.

Yoder, B. L. (2012). Engineering by the Numbers. *American Society for Engineering Education (ASEE),* Washington, DC. Available at http://www.asee.org/papers-and-publications/publications/collegeprofiles/2011-profile-engineering-statistics.pdf.

Zapata-Rivera, D. & Bauer, M. (2012). Exploring the role of games in educational assessment. In M.C. Mayrath, J. Clarke-Midura, D.H. Robinson, G. Schraw (Eds.), *Technology-based Assessments for 21st Century Skills: Theoretical and Practical Implications from Modern Research*. Charlette, NC: Information Age Publishing, Inc.

Ziegler, M. F., Paulus, T., & Woodside, M. (2014). Understanding Informal Group Learning in Online Communities Through Discourse Analysis. *Adult Education Quarterly*, *64*(1), 60-78.

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1998-2005	Program Director; Teacher Fannie Lou Hamer Freedom High School Bronx, NY	
2005-2007	School Director; Lead Teacher City Arts and Technology High School San Francisco, CA	
2006-2009	Director of Educational Program Development; Instructional Coach Envision Schools San Francisco, CA	
2009-2016	Doctor of Education Candidate Graduate School of Education Harvard University	
2009-2012	Graduate School of Education Harvard University	Ed.M. (*Learning and Teaching*)
2009-2011	Co-Director Cambridge-Harvard Summer Academy Harvard University	
2010-2015	Teaching Fellow Harvard University	
2011-2014	Research Assistant Project Zero Harvard University	
2011-2014	Consultant Envision Learning Partners Oakland, CA	
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